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كلية الدراسات العليا

التاريـــخ: / /

نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية وقوانين الجامعة الأردنية وأنظمتها وتعليماتها لطلبة الماجستير

أنا الطالب: ضياء علي خليفه العبداللات الرقم الجامعي: (8080194)

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عنوان الرسالة:
Effects of improved treatment in Khirbet As-Samra plant and its effects on the recipient water and irrigated soils -An environmental impact study-

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توقيع الطالب: ضياء التاريخ: 10 / 5 / 2011

EFFECTS OF IMPROVED TREATMENT IN KHIRBET AS SAMRA PLANTAND ITS EFFECTS ON THE RECIPIENT WATER BODIES AND IRRIGATED SOILS
-AN ENVIRONMENTAL IMPACT STUDY-

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This Thesis was submitted in Partial Fulfilment of the Requirements of the Master's Degree in Environmental and Applied Geology.

Faculty of Graduate Studies
The University of Jordan

May, 2011

Committee Decision

This thesis (Effects of improved treatment in Khirbet As-Samra plant and its effects on the recepient water bodies and irrigated soils–An environmental impact study -) was successfully defended and approved on 26th of April 2011.

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Dedication

To my parents, sister and brothers with love

To my real friends

To everyone support my success

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Finally, I would like to thank the many others who helped in the successful realization of this thesis.

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List of Abbreviations

μS/cm: Micro Siemens per centimeter.

A1-2: Na'ur formation.

A3: Fuheis formation.

A4: Hummar Formation.

A5-6: Shueib Formation.

A7: Wadi Es Sir Formation.

A11: Wadi Fill Aquifer.

asl: above sea level.

AG: Ain Ghazal

A.V: average.

B1: Wadi Ghudran Formation.

B2: Amman Formation.

B3: Muwaqqar Formation.

B4: Shallal Formation.

B5: Rijam Formation.

BOD5: Biochemical Oxygen Demand, 5-day, usually reported as milligrams per liter or kilograms per m^3.

COD: Chemical Oxygen Demand, usually reported as milligrams per liter or kilograms per m^3.

Cm: Centimeter.

DAF: Dissolved Air Flotation.

E: East (direction).

EC: Electrical Conductivity.

GTZ: German Agency for Technical Cooperation.

Ha: Hectares

Hr: Hour.

JTM: Jordan Transverse Mercator.

K: Kurnub Sandstone Group.

KAC: King Abdullah Canal

KTD: King Talal Dam

KS: Khirbet As Samra

km^2: Square kilometer.

L: Litter.

m: Meter.

m^3: Cubic meter.

MCM: Million Cubic Meters.

meq/l: Mille equivalent per liter.

mg/l: Mille gram per liter.

mm: Millimeter.

MOA: Ministry of Agriculture.

MWI: Ministry of Water and Irrigation.

N: North (direction).

N.A: Not Analyzed

NRA: Natural Resources Authority.

NWMP: National Water Master Plan.

ppm: part per million.

S: South (direction).

SI: Saturation Index.

TDS: Total Dissolved Solids.

USGS: United States Geological Scurvies.

UTM: Universal Transverse Mercator.

W: West (direction).

WAJ: Water Authority of Jordan.

WERSC: Water and Environmental Research Study Centre.

WHO: World Health Organization.

WGS: World Geodetic System.

WMO: World Meteorological Organization.

WTW: Wisseuschaftlich Technische Werhstaetten

WWTP: Wastewater Treatment Plant.

Yr: Year.

Z: Zarqa group aquifer**.**

EFFECTS OF IMPROVED TREATMENT IN KHIRBET AS SAMRA PLANTAND ITS EFFECTS ON THE RECEPIENT WATER BODIES AND IRRIGATED SOILS
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Abstract

In 2008 a new wastewater treatment plant for the Amman Zarqa area was established. This new plant is a mechanical one, contrary to the old treatment plant which depended on the natural stabilization ponds principles.
The main aim of this study is to evaluate the effects of the newly established wastewater treatment at Khirbet As Samra on the recipient water bodies namely; Wadi Dhuleil, Zarqa River, King Talal Dam and the areas lying downstream of King Talal Dam. Samples of water from Khirbet As Samra outlet and along Zarqa River to King Talal Dam were collected and analyzed. The concentrations of the different measured parameters along the river from the treatment plant to the King Talal Dam have shown to be improved. The obtained results concerning BOD and COD in addition to physicochemical parameters defined the water quality improvements such as strong reductions in the BOD and COD values and other pollution parameters in comparison with the values of the old treatment plant waters.
These improvements reflected positively on the environmental situation along Zarqa River, in King Talal Dam water and downstream where the water is used in irrigation.

1 Introduction

A great part of Jordan (about 90%) is located in arid and semi arid climate which entails the country its limited water resources, in particular its groundwater resources. Water in semiarid countries is becoming an increasingly scarce resource and planners are forced to consider treated wastewater as a choice in their water management strategies.

In most countries of the Eastern Mediterranean region, including Jordan, there is an increasingly and pressing need to conserve and protect water resources.

Water resources in Jordan depend mainly on rainfall precipitating during the winter season. More than 90% of the territory rainfall is flashy irregular and is below 200 mm per year. Only about 2% of the country receives a yearly rainfall exceeding 350 mm. So, agriculture is heavily depending on irrigation. Population growth rate of about 2.4 per cent is very high and is considered of the highest rates in the world that impose a challenge to achieve balance between resources and population. The demand for water in this arid country is high and steadily growing with all sectors of domestic, industrial and agricultural uses competing for limited supplies of costly water (MWI, open files).

Due to the limitation of surface water resources in Jordan, the groundwater basins are subjected to over- exploitation caused by extensive over pumping from wells owned by governmental and private sectors to supply water for drinking, industrial and agricultural purposes which had increased significantly in the last few decades. Groundwater forms the main water resources in Jordan.

Since the early 1980s, Jordan has worked to manage irrigation with treated wastewater by either discharging it to the environment where it mixes with freshwater or indirectly to be reused downstream along the wadis, or to irrigate restricted crops

such as cereal, fodder, forest trees and fruits. Official records of the Ministry of Water and Irrigation (MWI, 2001) show that more than 100 thousand donums were irrigated with the treated wastewater effluent of the existing treatment plants.

In 1985, As Samra wastewater treatment plant (stabilization ponds); the largest natural treatment plant in the Middle East, was constructed to serve the capital city Amman, Zarqa city and Ruseifa towns. It used to serve more than 2 million people and treated 76.0% of the wastewater generated in Jordan. As Samra plant consisted of three parallel trains, with a total water surface area of 181 ha, each train consists of two anaerobic ponds, four facultative ponds and four maturation ponds, so that, 10 ponds in each train are operated in series (WAJ, 2006).

Recently, the wastewater treatment at Khirbet As Samra (KS) has been changed from stabilization ponds type of treatment to mechanical type. The quality of the effluents changed dramatically to the better. The new wastewater treatment plants began operating in early 2008. The water quality and pollution loads in the basin are therefore set to improve. There is consequently a new opportunity for restoration of the Zarqa River and King Talal Dam (KTD). Such actions will create benefits for the ecosystems associated with the river and KTD water, for the well-being of the people of the basin and for the economy of the framers and the country.

1.1 Aims of Study

The main objective of this study is to quantitatively evaluate the quality changes of the effluents of KS and the changes which has taken place during the last 3 years in the recipient water bodies; Zarqa River and King Talal Dam and in the soil irrigated with the mixture of effluents of KS and other waters in the Jordan Valley area.

The study will therefore quantify the positive impacts and measure the environmental improvements along Zarqa River, in King Talal Dam and in the irrigated areas in the

Jordan Valley as a result of improved effluent quality of KS. It will also provide a framework for sustainable management of Zarqa River and lands irrigated with its water.

1.2 Previous studies

Numerous studies for different purposes have been conducted in the study area, to work out the geology, hydrology and hydrogeology of the area to determine natural groundwater recharge, aquifer characteristics and sources of pollution and to obtain information on the water resources development of this basin.

MacDonald and Partners (1965) conducted a study on the hydrogeological situation in the study area in the content of constructing agricultural irrigation projects.

The German Agency for Technical Cooperation Ltd. (GTZ), prepared a detailed hydrological work for the whole country including the study area (NWMP, 1977).

Salameh, E. (1981) studied the hydrogeology and hydrochemistry of the catchment area of the King Talal Reservoir and delivered a baseline set of data of the groundwater quality in the pre-development area.

Salameh, et al. (1987) studied the effects of Khirbet As-Samra (KS) effluent on the water quality of wadi Dhuleil and Zarqa River. This study concluded that the status of parameters indicates that KS effluent had a negative impact on the water quality of the river. Visualized implications to the water quality of the Zarqa River and King Talal Reservoir have been assessed.

USAID & WAJ, (1989) prepared three reports to cover Yarmouk, Azraq and Amman Zarqa Basins. The main purpose was to evaluate the available water potential. This study showed that the deterioration of groundwater in some parts of Amman Zarqa Basin is serious and effective action has to be undertaken to stop further deterioration.

Al-Kuisi ,(1992) studied the inorganic chemical and physical changes of the surface and groundwater qualities in Amman –Zarqa- Sukhna areas of the Zarqa River Basin, as a result of urbanization, industrialization, and increasing agricultural activities.

Awad (1997) carried out a study on “Environmental study of the Amman-Zarqa Basin”. The main objectives of this study were to evaluate the water quality in Zarqa River, efficiencies of both the old Khirbet As Samra treatment plant and the industrial treatment plants. The main results of this study were that the water quality of Zarqa River is poor and is not even suitable for unrestricted irrigation.

Bajjali, (1997) determined the origin of groundwater salinity in Dhuleil - Hallabat and Samra areas of Jordan”. The main purpose of this study was to define the characteristics of the groundwater hydrochemistry and to define the sources of salinity in some wells. The study showed that irrigation return flows were the main source for salinization problems and that the occurrence of nitrate (NO_3) in the groundwater is due to the use of inorganic fertilizer.

USAID, (2001) prepared a report for resource policy support plan for managing water reuse in the Amman-Zarqa Basin and the Jordan Valley. The main goals of this study were to use reclaimed water, to exchange for present and future uses of freshwater, and to maximize the use of reclaimed water resource. The main results reached by this study were that the volume of reclaimed water available in Amman-Zarqa Basin is expected to grow from 60 * million m^3/yr in 2000 to more almost 180 *million m^3 by 2025. In addition, the main constituents of concern for irrigated agriculture are salts, microbiological, contamination, and nitrogen. The levels of trace elements and metals in the effluent are lower than those specified by the relevant Jordanian Standards.

MWI, (2004) concluded that the quality of the treated wastewater is of vital importance as it becomes in contact with the food chain. Therefore, intensive investigation concerning the quality of the effluents and the effect of these effluents

on soil properties such as EC, pH and plants irrigated with wastewater must be performed.

1.3 Location

Amman Zarqa Basin is about 4025 km^2. With a variety of the climates ranging from wet to dry and different landuse patterns and large changes of habitat and with respect to the areas socioeconomic and agricultural importance.

The studied portion of Zarqa River extends from the discharge site of KS through Al-Hashimiya village and the cultivated areas along the banks of the Zarqa River to King Talal Dam (KTD) and further downstream to the Jordan Valley, Figure (1).

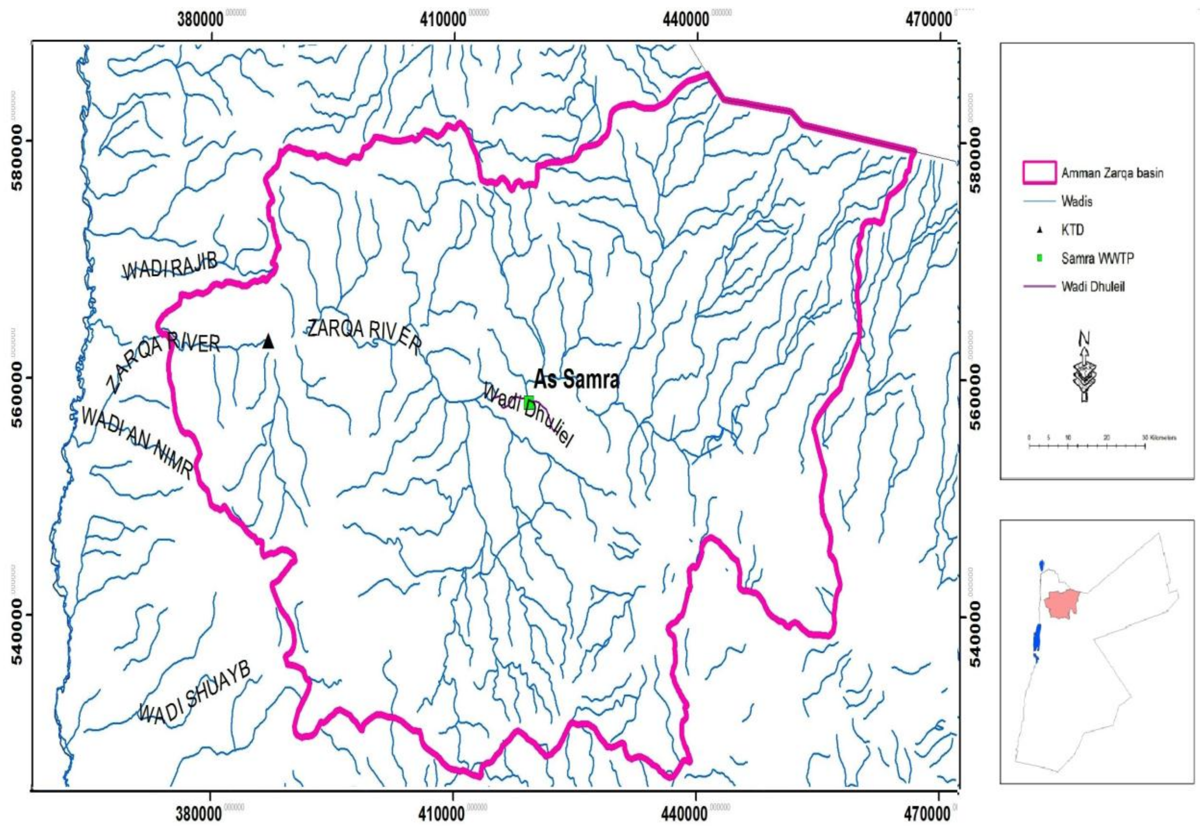


Figure 1: Location of the Zarqa River catchment in Jordan

(JTM, coordination), (MWI, open files 2010).

1.4 Topography

The area is a part of the western highlands of Jordan extending westwards to the Jordan Valley. The slope changes from west to east where hilly areas comprise a large part of the western and surrounding areas along the boundary of the basin. Altitudes gradually decrease towards the center of the basin and towards the outlet of the catchment into Jordan Valley near Deir Alla in the west from the center. The altitudes increase towards the northeast into Syria where the highest point of the basin lies at 570 m asl in Jabal Al Arab. The lowest point of the basin is about 240 m below mean sea level near Deir Alla**.**

1.5 Water resources

The main water resource in the study area is Zarqa River which consists of Wadi Dhuleil and Sail Zarqa that joins at Sukhna to form Zarqa River. The second water resource in quantify originates from the treated wastewater of KS and Jarash wastewater treatment plants.

1.6 Methodology

1.6.1 Literature review and data collection: Data available related to geological, hydrogeological, hydrological, hydrochemical, landuse and other related environmental issues, that are documented in technical reports, papers, journals or other references were collected and evaluated to serve the objectives of the study.

1.6.2 Field work: Geological, hydrogeological, hydrological, hydrochemical and other related information and field measurements were collected during this work in order to confirm available data collected and to compile the missing data. Water sampling sites were carefully selected to cover the study area and to fulfill the main aims of this study. Water samples were collected in the years of 2009 and 2010. The chemical analysis for the major cations, anions and heavy metals were carried out at the Laboratories of the University of Jordan and at the Laboratories and Quality Department of the Ministry of Water and Irrigation (MWI).

2 Geology and structure

2.1 Geological setting

The outcropping formations in Amman Zarqa Basin range in age from Triassic to recent (Macdonald & Partners, 1965). Hydrogeological map of the basin and Table (1) contains information on the different rock types and their hydraulic nature.

Table 1: Geological and hydrogeological classification of rock units in study area (modified after Margane et al. 2002).

System	Epoch	Group	Formation	Symbol		Lithology	Thickness	Aquifer unit
Quaternary	Holocene	Jordan Valley	Alluviam	Basalt	Qat	Soil, Sand, Gravel	>300m	Alluvium (Aquifer)
Upper Cretaceous	Mastrichtain	Balqa	Muwaqqar	B3		Chalk, Marl and chalky limestone	60-70m	Poor (Aquifer)
	Campanian		Ammn-Al Hisa	B2		limestone, chert, chalk, phosphate	20-140m	Good (Aquifer)
	Sanionian		W.Umm Ghudran	B1		dolomitic marly limestone, marl, chert, chalk	20-90m	Aquitard
	Conianion							
	Turonian	Ajlun	Wdi As Sir	A7		Limestone, dolomitic lst, chert, marl	60-340m	Good (Aquifer)
			Shueib	A5-6		marl, Limestone	40-120m	
	Cenomanian		Hummar	A4		Limestone, dolomite	30-100m	
			Fuheis	A3			30-90m	Semi (Aquifer)
			Na`ur	A1-2		Limestone, dolomite, marl	90-220m	Bad (Aquifer)
Lower Cretaceous		Kurnub	Subeihi	K2		sandstone, shale	120-350m	Kurnub (Aquifer)
			Aarda	K1		sandstone, shale		
Jurassic		Zarqa	Azab	Z		siltstone, sandstone, limestone	0->600m	Zarqa (Aquitard)
Triassic			Ramtha			siltstone, sandstone, shale, limestone, anhydrite, halite	0->1250m	

2.1.1 Jurassic - Triassic rocks:

Zarqa Group consists of sandstone, siltstone, shale, dolomite and dolomitic limestone, marl, gypsum and intercalation of volcanic ash. Its thickness reach up to 1000 m as encountered at south of Amman (Bandel, K. And Khoury, H, 1981).

2.1.2 Lower Cretaceous rocks:

The Kurnub Group (K) crops out in Baqa`a depression and along the axis of Amman and Suweilih anticlines and at the lower researches of Wadi Zarqa itself. It consists of white, gray and multicoloured sandstone (fine-medium and coarse grained) with red silts, shales and dolomite streaks. Its thickness ranges from120 m to 350 m and is considered as a major aquifer in the study area (Mc Donalds, 1965).

2.1.3 Upper Cretaceous rocks:

The stratigraphic sequence found in this area was divided by Quennell (1951) into two groups:

- The Ajlun Group
- The Balqa Group

2.1.3.1 The Ajlun Group:

The Ajlun Group overlies the Kurnub Group, and includes all the marine sediments which is mainly consisting of limestone, dolomite, marl, shale and sandstone and is subdivided into five formations:

- The Na`ur Formation (A1-2)
- The Fuheis Formation (A3)
- The Hummar Formation (A4)

- The Shueib Formation (A5-6)
- The Wadi As-Sir Formation (A7)

2.1.3.1.1 The Na`ur Formation consists mainly of limestone, gray and pink in colour, hard crystalline coarse-grained and fractured, and is considered as a poorly developed aquifer with a thickness range from 200 to 230 m (Bender, 1968).

2.1.3.1.2 The Fuheis Formations consists of marl, limestone, marly limestone and shale, and is considered as semi aquifer with a thickness of 60-80 m (Mc Donalds, 1965).

Both Formations crop out in the northern and western parts of Amman-Zarqa Basin.

2.1.3.1.3 The Hummar Formation forms the important lower good aquifer that forms a narrow outcrop in the northern part of the study area (along the Zarqa River). It comprises limestone and dolomitic limestone. Generally, the thickness of this Formation is between 30 and 60 m.

2.1.3.1.4 The Shueib Formation acts as an aquiclude between Hummar (A4) and Wadi Es Sir Aquifers in the Amman Zarqa groundwater basin. Its crops out in the north-western parts of Amman Zarqa Basin with a thickness of about 200 m consisting of marl and marly limestone (Mc Donalds, 1965).

2.1.3.1.5 The Wadi As-Sir Formation acts as a good aquifer. It covers the major parts of the study area and consists of about 100 m thick bedded limestone with chalky limestone interactions and occasional chert beds and nodules (Mc Donalds & partners, 1965).

2.1.3.2 The Belqa Group:

The Belqa Group overlies the Ajlun Group and is subdivided into five formations (Abed, 2000):

- A Wadi Ghudran Formation (B1)
- Amman Formation (B2)
- Muwaqqar Formation (B3)
- Shallal Formation (B4) and Rijam Formation (B5) which are not found in the study area.

2.1.3.2.1 Wadi Ghudran Formation is considered as an aquitard and consists mainly of chalk, marl with an average thickness of about 20 m, but it is missing in many places of the study area (Mc Donalds, 1965).

2.1.3.2.2 Amman Formation is an excellent aquifer. It crops out in most parts of Amman Zarqa Basin. It consists of limestone and chert interbedded with phosphatic layers and marl, with a thickness of about140 m. Hydraulically it is connected with Wadi Es-Sir Formation to form one major aquifer (Mc Donalds, 1965).

2.1.3.2.3 Muwaqqar Formation is an aquiclude and crops out in the south-eastern parts of Amman Zarqa Basin. It consists of marl, chalk and chert, with a thickness ranging from 60 to 80 m (Mc Donalds, 1965).

2.1.4 Wadi Fill Deposits

The bed and terraces of the Wadi Zarqa consist of sands, gravels and some clay with a thickness of up to 20 m. Then alluvial deposits overlie older rock units such as B2-A7, A5-6 and basaltic rocks.

1.1.5 Basalts

The north-eastern parts of the study area are covered by thick basaltic rocks of Tertiary and Quaternary ages. They cover the older rocks consisting mainly of the B2-A7 Formations (Bandel and Khoury, 1981, Mc Donalds, 1965). However, they also cover older alluvium deposits along wadi cover e.g. Dhuleil, and along ancient slopes with alluvial and colluvial deposits.

2.2 Structure

In Amman-Zarqa study area generally low dips of strata and gentle folding are found, except for the flexures and their associated faults. That marked the important synclines of Wadi Sayih and Muasher in the south and south-central parts. North of the Muasher syncline there appears to be another turndown of fault. The main geological structures types occurring in Amman Zarqa Basin are, Figure (2):

- Sweima- Amman Structure.
- Suweilih Structure.
- Zarqa River Structure.

2.2.1 Sweima - Amman Structure

This structure starts in the north-eastern corner of the Dead Sea as a vertical or reverse fault with down throw north western flank. The down throw, in the Jordan Valley area is about 500m. Along this NE-SW extending structure, the down through decreases in a NE direction and the faulted part of it in the Jordan Valley area turns further east in Na`ur – Amman area.

Flexure, further to the NE, in Zarqa – Hallabat area develops into a monocline and dies out further east. Along the down faulted and downflexured trough of Sweima-Amman structure, springs have developed discharging water from all aquifers of

Zarqa, Kurnub, A1-6, B2A7 and alluvium. Mixing of different aquifers waters along this structure by upward or downward movement is present.

2.2.2 Suweilih Structure

This structure is similar in type and history to Sweima- Amman structure. It starts at the NE corner of the Dead Sea and trends NNE- SSW. It commences as a fault and develops gradually into a flexures further NNE. In salt area it becomes a flexure, further northeast it forms and in monocline in Rihab area it dies out. Along its course, the Baqa’a geomorphologic depression has formed and exposed the deep aquifers of the Zarqa and Kurnub group.

2.2.3 Rumeimin Fault

This fault trends E-W, starts and dies out normal within the study area, and does not have major hydrological implications, due to its very small down throw.

2.2.4 Zarqa River Structure

A small anticlinal bending exists within the E-W trending part of Zarqa River Valley. This structure could be explained as a tectonic factor of the area. The fault exists were a rotation of about 20˚ has occurred between the two blocks north and south of Zarqa River. The movement is supposed to have taken place in quaternary time (Atallah and Mikbel, 1992).

Low amplitude anticlinal bending, along which crest the Zarqa River has cut its bed as a result of the weakly cemented sandstones of the Kurnub group. The structure and the erosion along its axis allowed the formation of springs and the discharge of Kurnub and Zarqa group into the Zarqa River.

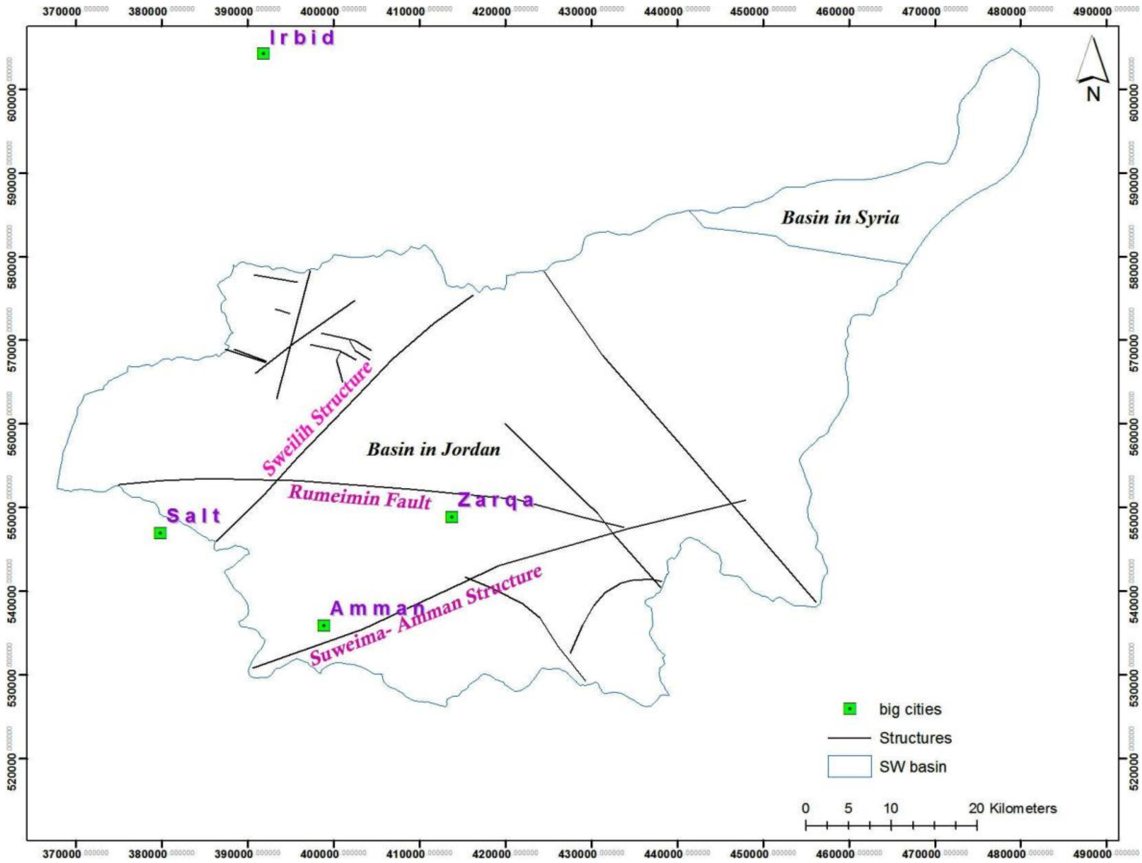


Figure 2: Structure map for study area (MWI, open files 2010).

3 Hydrogeology

3.1 Hydrogeological setting

The hydraulic system of Amman Zarqa Basin is controlled by the geological set-up, which also controls the recharge level, movement, and discharge of the groundwater. The five aquifer systems in Amman Zarqa Basin area, Figure (3) are:

1. **Zarqa Group Aquifer (Z**); consisting mainly of sandstone and siltstone. It is the oldest aquifer which crops out in the study area along the lower reaches of Zarqa River. This aquifer contains brackish water and is hydraulically interconnected with the overlying Kurnub aquifer.
2. **The Lower Cretaceous Aquifer (Kurnub Sandstone Group) (K)**; mainly consisting of sandstone. It crops out in the western parts of the basin in Baq'a depression, and along the E-W trending course of Zarqa River.
3. **Upper Cretaceous Aquifer (Limestone) (A1-A6)**, which consists of Hummar (A_4) and Na'ur (A_{1-2}) Formations.
4. **Amman -Wadi Es Sir Aquifer (B2-A7)**, consisting of limestone, chert and phosphatic rocks. This aquifer is of Upper Cretaceous age and forms the major aquifers system in the study area.
5. **Wadi Fill Aquifer (A11)**, which consists of basalts, and alluvial deposits, found as wadi-fill in Wadi Dhuleil, along Zarqa River and in the north-eastern parts of the basin.

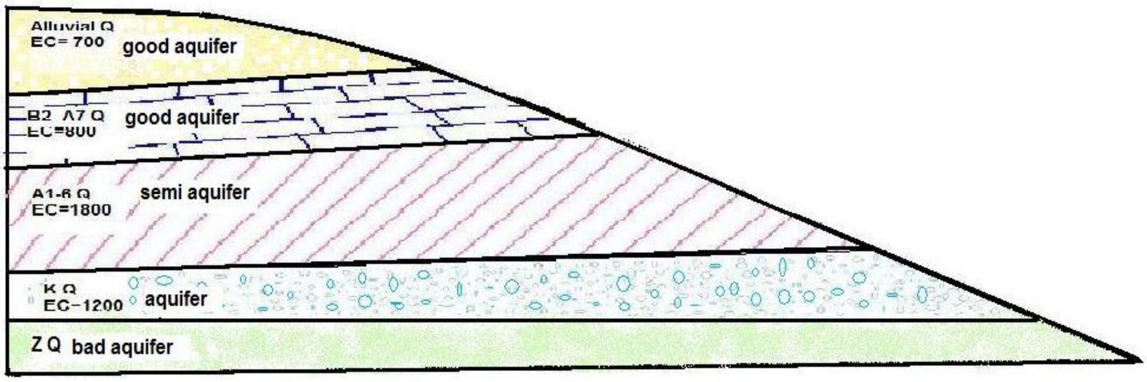


Figure 3: General setup of aquifers types in study area.

3.2 Groundwater movement

The groundwater movement is effected by hydraulic parameters such as recharge and discharge areas, permeability of aquifer and the hydraulic gradient.

The direction of groundwater flow in the shallow aquifers, B2 A7 and alluvium from S-W where recharge occurs in the N-W part of the study area, and along to the N-E towards Wadi Dhuleil and Zarqa River courses (Salameh and Bannayan, 1993).

Groundwater originating in the eastern part flows in a westerly direction. The groundwater originating from western highlands of Amman and its surroundings flows in an easterly direction. Both the groundwater currents meet in Zarqa – Sukhna area and discharge along the course of Zarqa River.

3.3 Groundwater recharge and discharge

In stable geologic conditions, the recharge of an aquifer equals its discharge. This implies that the water table, under equilibrium, fluctuates about the same level (Salameh, 1985).

The recharge to aquifers in study area can be direct recharge by the infiltration of rainfall, or indirect by lateral or vertical flow from others aquifers through fractures or weaken zones. In addition, return flows contribute presently to the recharge process of the shallow aquifer in the study area, Figure (4).

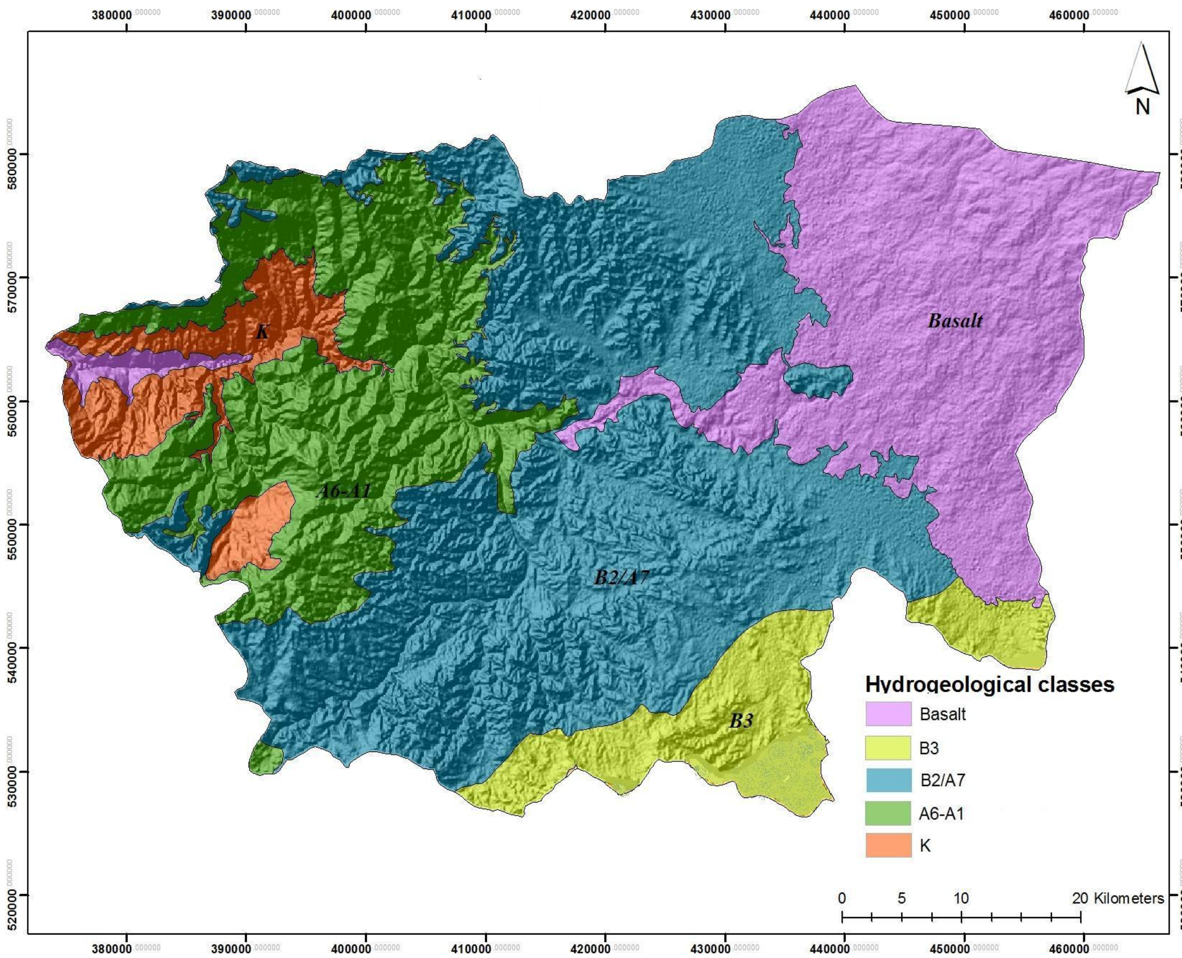


Figure 4: Generalized hydrogeological map of the study area (MWI, open files 2010).

Recharge to the eastern parts of the study area comes from precipitation over the area and partly from Jabel Druz. Flood waters flowing within the area and irrigation activities, especially in Dhuleil area, contribute to the groundwater recharge. Recharge in the western part takes place along the highlands of Amman and its surroundings and along wadi courses which discharge flood water (transmission losses).

Discharge of aquifers can be in the form of springs, wells, seepages and vertical flows to other aquifers. In study area, the major springs are:

- Amman-Wadi Es Sir Formations and recent alluvium, the springs are: Ras el Ain, Ruseifa, Ain Ghazal and Tabarbur.

- Hummar and Na'ur aquifers major springs are: Nimra, Zarbi, Fawwar, Maghasil and Qunayyah.
- Kurnub sandstone springs are: Thermal spring in Deir Allah, Subeihi and Hammam Jarash.

The analyses of these springs are shown in Table 2, 3, and 4 (WERSC, open files).

Table 2: Chemical analyses of Amman - Wadi Es Sir Springs, units (meq/l or as mentioned in the raw) (WERSC, open files).

Amman -Wadi Es Sir Formation																	
	Ras El Ain			Ruseifa				Authority aquifer			Schn-eller	Ain Ghazal				Tabarbur	
	Jan	Feb	Mar	Jan	Feb	Mar	Apr	Jan	Feb	Mar	Jan	Jan	Feb	Mar	Apr	Jan	Feb
NO3	0.73	0.7	0.69	0.94	0.57	0.18	0.99	0.03	0.03	0.04	1.08	1.46	0.01	0.16	0.8	0.43	0.43
HCO3	5	3.67	3.88	3.78	4.22	2.28	1.82	4.54	5.15	5.51	5.25	5.37	2.61	2.5	17.13	3.78	3.78
SO4	0.29	0.1	4.12	0.78	0.568	0.8	0.42	1.4	0.2	1.32	0.52	0.57	0.57	0.23	9.8	0.25	0.25
Cl	2.35	4.31	0.51	2.55	2.3	1.35	3.48	2.9	1.47	0.25	3.24	4.2	1.26	0.08	0.18	0.91	0.91
Ca	4.21	3.87	4.06	4.2	3.8	2.2	2.5	2.9	3.08	2.8	4.7	1.4	1.5	1.46	7	2.6	2.6
Mg	2.47	1.88	2.28	1.2	1	0.6	1.7	2.7	2.47	3	2.5	7.1	2	1.5	4.2	0.91	2.6
Na	2.09	3.65	3.34	2.45	1.88	1.24	2.47	1.02	0.97	1.02	2.78	3.64	0.77	2.1	0.32	5.37	0.51
K	0.08	0.16	0.15	0.09	0.36	0.18	0.1	0.1	0.07	0.1	0.2	0.26	0.01	0.69	0.1	0.13	0.13
EC µs/cm	862	990	910	851	900	416	915	601	685	607	970	1190	574	588	2550	536	536
pH	7.67	8.25	7.57	7.08	8.25	7.71	7.7	7.01	8.5	8.18	7.05	6.57	8.05	8.25	7.39	7	7
T °c	22.4	21.4	21.5	20.5	19.1	12.5	20.6	28.6	24.6	29	23.3	20.8	26	25.2	27	25.7	25.7
I mg/l	-	-	-	0.001	0.028	0.02	0.0001	-	-	0.0004	-	0.01	0.0001	0.0001	-	0.006	0.001
Br mg/l	-	-	-	0.02	0.269	0.14	0.52	-	-	0.36	-	5.15	0.001	0.002	-	1.21	1.21
F mg/l	-	-	-	0.06	0.36	0.25	0.29	0.46	-	0.30	0.46	1.47	0.277	0.22	-	1.54	1.54
COD mg/l	96.9	5.11	46.94	-	-	-	-	1.4	5.11	9.72	1.4	5.07	-	-	-	-	5.07
PO4	2.05	0.06	0.083	0.02	2.41	0.01	0.04	0.03	0.04	0.754	0.019	0.10	0.014	0.42	9.62	0.093	0.10

Table 3: Chemical analyses of Hummar-Na`ur springs, (meq/l or as mentioned in the raw) (WERSC, open files).

Hummar - Na`ur Formation Nimra Spring											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NO3	0.8	0.8	0.83	0.84	0.82	0.57	0.81	0.81	0.88	0.98	0.97
HCO3	2.87	3.367	7.8	2.73	3.03	2.65	2.38	2.64	2.36	2.44	2.35
SO4	3.07	2.27	4.5	2.76	4.5	4.54	3.74	3.5	2.72	2.62	3.39
Cl	10.58	10.85	10.6	9.94	10	11.6	11.2	11.4	10.6	10.75	10.05
Ca	5.433	5.45	5.5	5.648	7.1	5.3	18.18	18.35	5.02	5.61	5.1
Mg	5.4	5.5	5.5	3.92	2.9	6.1	5.52	5.42	5.42	4.63	5
Na	7.39	6.58	6.83	6.9	7.38	8.26	5.32	5.71	6.03	6.17	6.63
K	0.163	0.15	0.179	0.215	0.1828	0.95	7.47	0.15	0.18	0.18	0.18
EC µs/cm	1820	1510	1630	1485	1720	1873	1880	1980	1800	1770	1700
pH	7.84	6.78	7.36	7.79	7.52	7.54	7.67	7.55	7.61	7.56	7.43
T˚c	24	23	25	25	24.6	24.4	22	23.1	22.9	19.8	24.4
I mg/l	0.035	0.095	0.072	0.066	0.004	0.05	0.001	0.001	0.029	0.026	0.021
Br mg/l	4.84	7.78	4.66	4.272	0.387	0.062	0.455	0.566	1.06	1.28	2.518
F mg/l	0.18	0.15	0.143	0.13	0.0088	0.02	0.047	0.046	0.51	0.401	0.244
PO4	1.87	0.011	0.057	0.03	0.69	1.06	0.018	0.073	0.21	0.087	0.142

Table 4: Chemical analysis for Kurnub springs (meq/l as mentioned in the raw) (WERSC, open files).

Kurnub Formation				
	Subeihi	Hammam Jarash		Thermal spring
	Jan	Jan	Feb	Jan
NO3	2.09	0.19	0.457	0.096
HCO3	5.7	7.71	9.12	6.78
SO4	0.843	11.98	5.82	9.4
L	5.65	14.25	13.7	14.39
Ca	8.26	13.59	13	13.1
Mg	2.04	6.27	5.4	6.3
Na	3.37	15.19	14.8	12.56
K	0.281	1.48	1.26	1.28
EC µs/cm	1270	3320	3180	2000
pH	5.39	6.4	6.56	5.63
T˚c	20.09	26.9	27.7	28.6
I mg/l	0.03	0.124	0.018	0.04
Br mg/l	2.48	1.499	0.39	8.9
F mg/l	0.329	2.43	0.078	10.7
PO4	-	0.087	2.48	0.099

4 Hydrology of the Study Area

The catchment area of Zarqa River to Deir Alla gauging station measures 4025 km²
and extends from the foothills of Jabel Druz to the Jordan River. Zarqa River has the second largest area of drainage basin and mean annual discharge in Jordan. The study portion of Zarqa River from Khirbet As Samra to KTD is shown in Figure (5).

The River consists of two main branches; Wadi Dhuleil, which drains the eastern part of the catchment area, and Sail Zarqa, which drains the western part. Both meet at Sukhna to form the Zarqa River. Naturally, the eastern branch drains only flood flows as a result of precipitation, whereas the western branch drains flood and base flows (Salameh, 1996).

Much evidence indicates that historically (geological), the river discharge of into Azraq Oasis and Wadi Sirhan in the east. In its recent history, retrogressive erosion diverts the flow direction in the Zarqa Sukhneh area to the west and allowed the river water to reach the Jordan Valley area and to discharge via the Jordan River into the Dead Sea (Salameh, 1996).

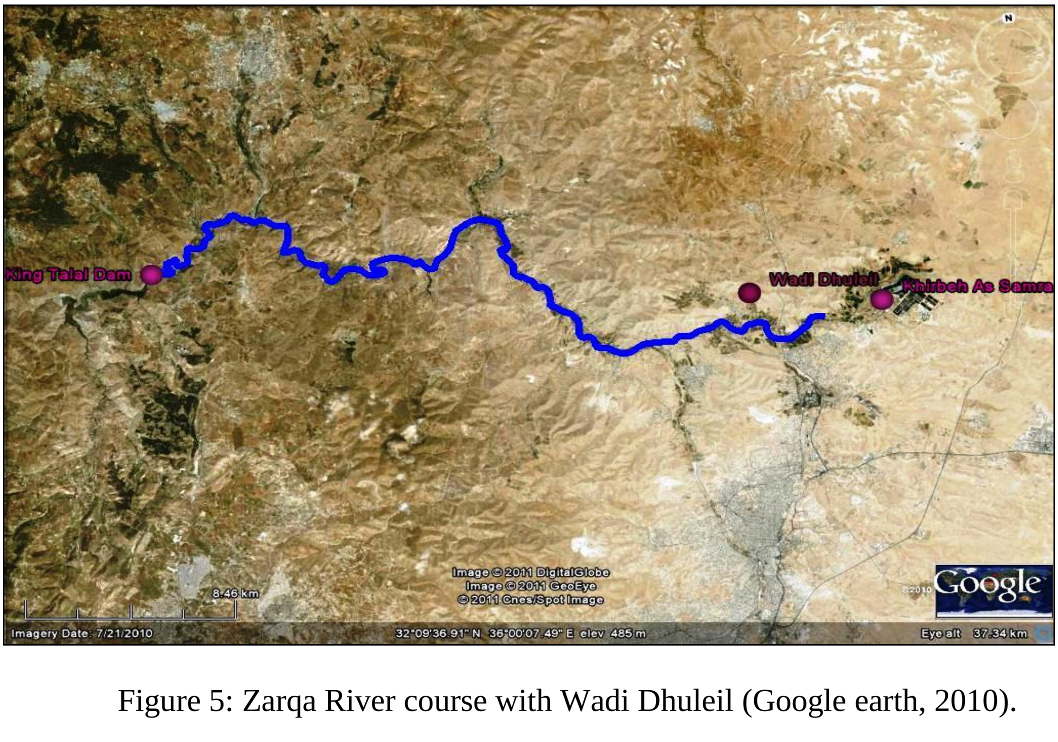


Figure 5: Zarqa River course with Wadi Dhuleil (Google earth, 2010).

Figure (6) shows the catchment area of Zarqa River which comprises around 65% of the country`s population and more than around 60% of it`s industries (MWI, open files). The urban wastewater are generally sewered and treated in different wastewater treatment plants to varying degree. Also, most industruies located in the catchment area treat their wastewaters before dischage into the surface water system, or to Kherbit As Samra for further treatment.

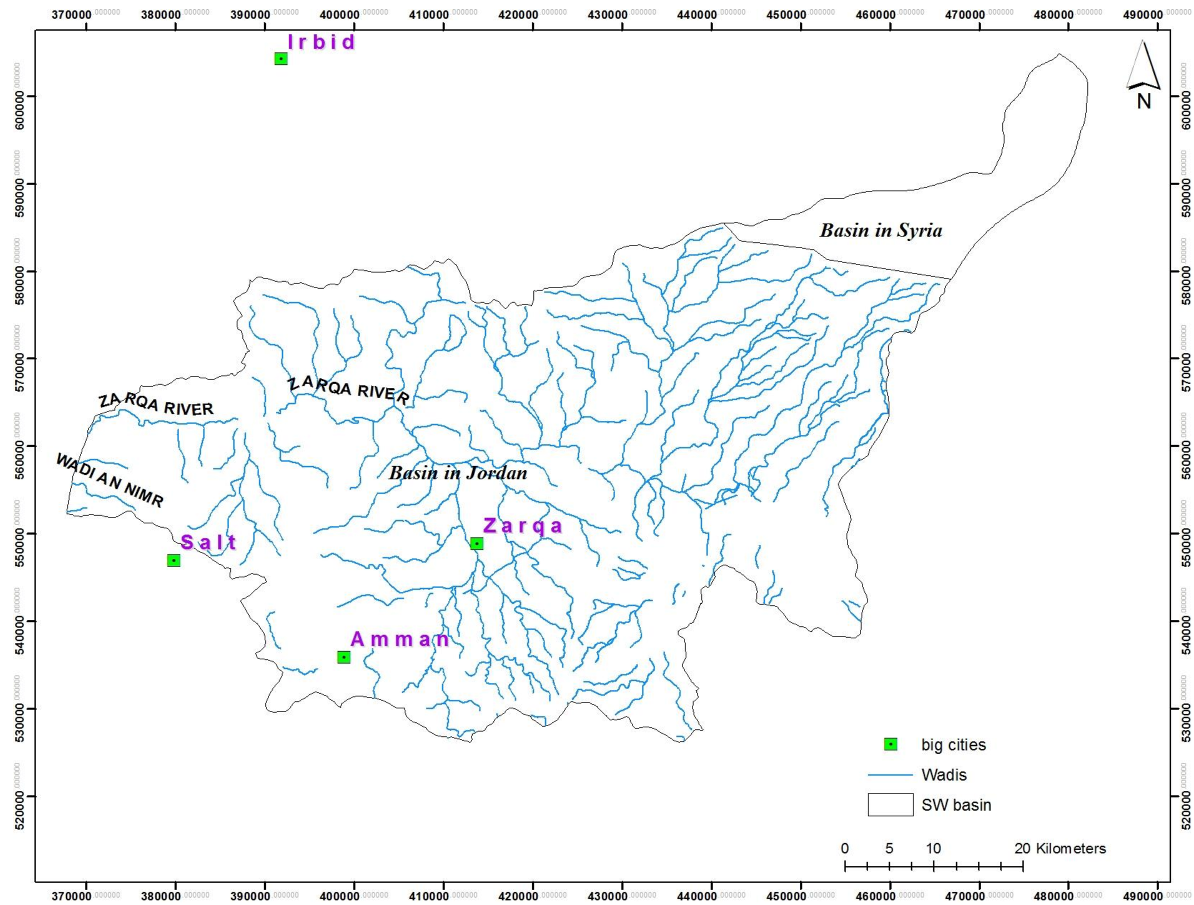


Figure 6: Catchment area of Zarqa River (MWI, open file 2010).

4.1 Hydrometeorological characteristic:

The hydrometeorological network in the area consists of rainfall, evaporation and runoff stations.

4.1.1 Climate

Jordan can be classified as semi-desert area, with only the western highlands enjoying a Mediterranean climate. Amman Zarqa Basin is bordered by the high lands in the west and the foothills of Jabal Al Arab in the Northeast.

The basin is a transitional area between semi arid highlands (west) and the arid desert (east). The climate is relatively temperate; cold and wet in winter with temperatures reaching a few degrees during the night, to hot and dry in summer with temperature reaching 35˚c at noon, but with average daily relative humidity of 15 – 30 % in the arid parts, which makes the heat more acceptable (Salameh,1996).

4.1.2 Precipitation

Rainfall is the main process of hydrological cycle, which plays a significant role in the water budget for the sources of water. It is governed by the topographical variation causing the uplifting of the humid wind currents and resulting finally in precipitation. Amman Zarqa Basin receives an average areal annual precipitation of 237 mm. The eastern catchment, which comprises around half of the total catchment area, receives an average amount of precipitation of 182mm/yr. The western catchment, comprising the highlands and the Jordan Valley area, receives an average precipitation rate of 397 mm/yr. Precipitation over the highlands may be in the form of snow; in the eastern part of the Basin it is generally rainfall (Salameh, 1996).

The highest amount of precipitation falls over the highlands of Salt and Amman. In an average year it reaches 550mm; it increase in a wet year to 750mm and decreases in a dry year to 350mm. In most eastern part of Basin the average precipitation in a normal year is 80 mm, increasing to 150 mm in wet year and decreasing to 50 mm in a dry

year (Salameh, 1996).

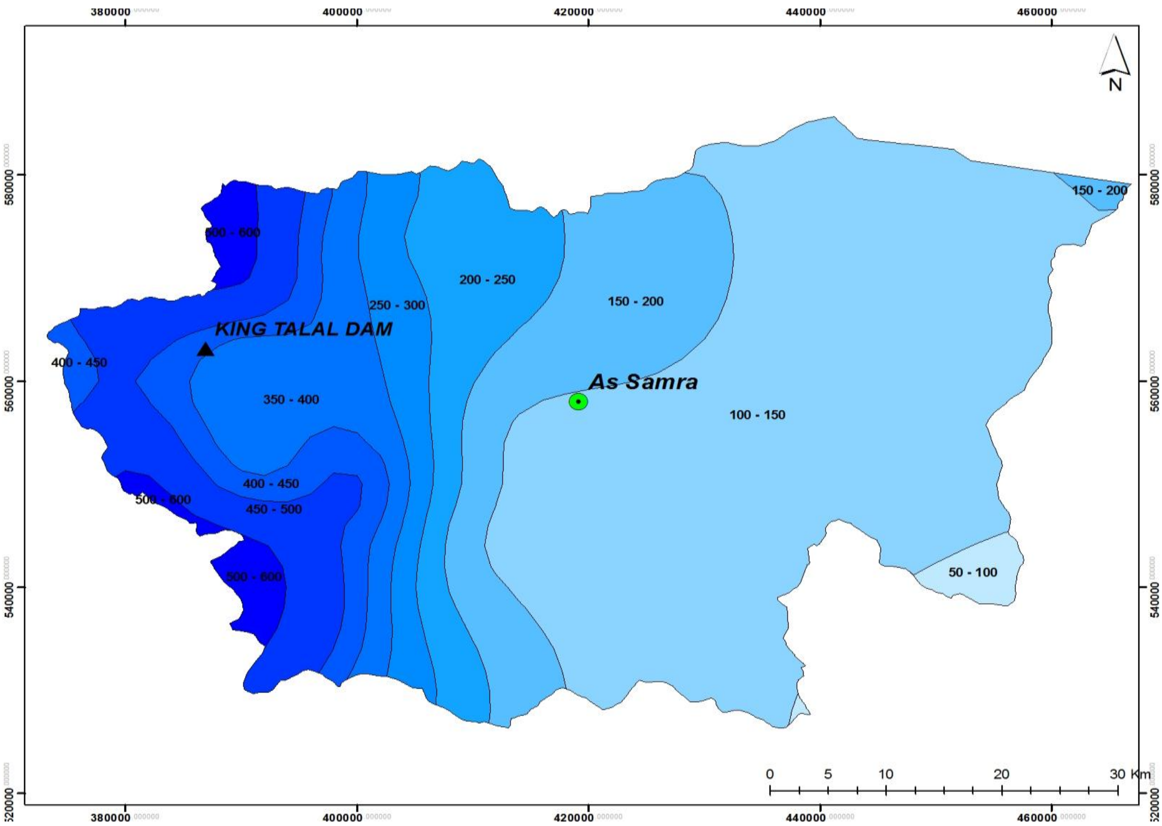


Figure 7: Long-term average rainfall distribution (mm/yr) over the study area (MWI, open file 2010).

4.1.3 Evaporation

Evaporation is a process by which water is transformed from a liquid state into water vapour requiring energy to provide the latent heat of vaporization (Chow et al. 1988). This takes place mainly from land surface, seas and oceans, and partly from the surface of rivers, lakes, moist soil, plant leaves (evapotranspiration) and ice. This process takes place when soil moisture is available for evaporation.

The potential evaporation ranges from 1600mm/yr along the western highlands, to 2000mm/yr in the eastern part of study area. Meanwhile, there is not enough water to satisfy the needs of the evaporation force of the climate, which is far less during the winter months than during the summer months, a fact which allows precipitation

water to infiltrate and recharge the ground water during the rainy season (Salameh,1996).

4.1.4 Runoff

The amount of water which flows on the earth surface along wadis. This amount is considered as an important element for computation of water budget of the study area. The amount of runoff mainly depends on factors, such as is soil permeability, slope, rainfall intensity, land use…etc. In Amman Zarqa Basin there are three main flow streams and many sub wadis Figure (8). Wadi Dhuleil (flood flows) draining the eastern parts of study area, Sail el Zarqa (flood and base flows) the western parts of study area and Zarqa River.

4.1.5 Groundwater recharge

Recharge of the groundwater takes place directly through direct infiltration via soils and indirectly along Wadi courses. Groundwater recharge has been calculated in many studies such as NWMP 1977, VBB 1971, BGR 1995 and MWI open files. The recharge calculations and estimates range from about 50 MCM/yr to110 MCM/yr.

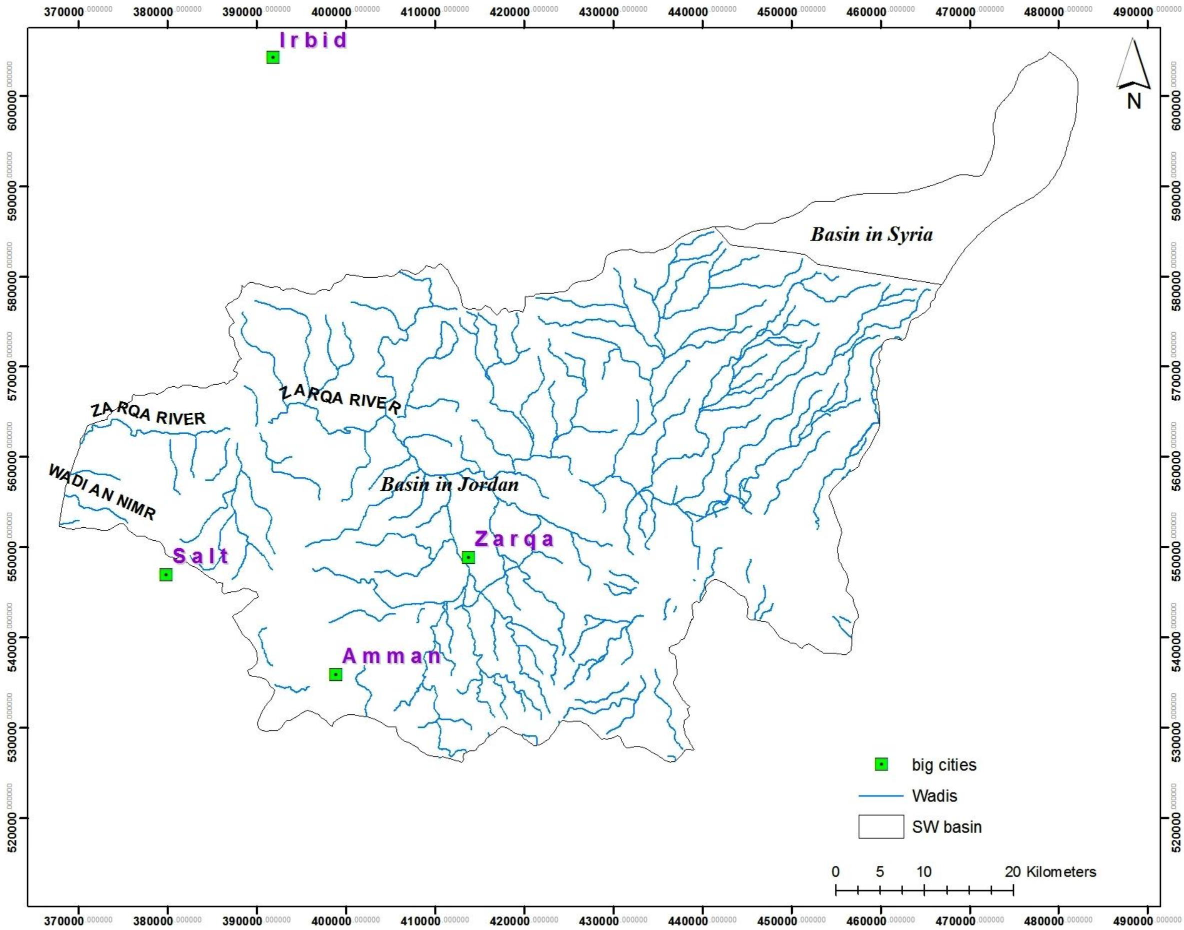


Figure 8: Drainage system of Amman Zarqa Basin (MWI, open file 2010).

5 Wastewater Treatment Plants in the Study Area

Zarqa River is one of the most important sources of surface water in Jordan, which carries more than 78% of the treated wastewater quantities (WAJ, 2006). Therefore, the future impacts on Zarqa River together with the increasing demand will partly determine a major part of water use in Jordan. The River is strongly affected by treated wastewater effluents originating from As Samra which are a vital resource of water in the Zarqa River basin.

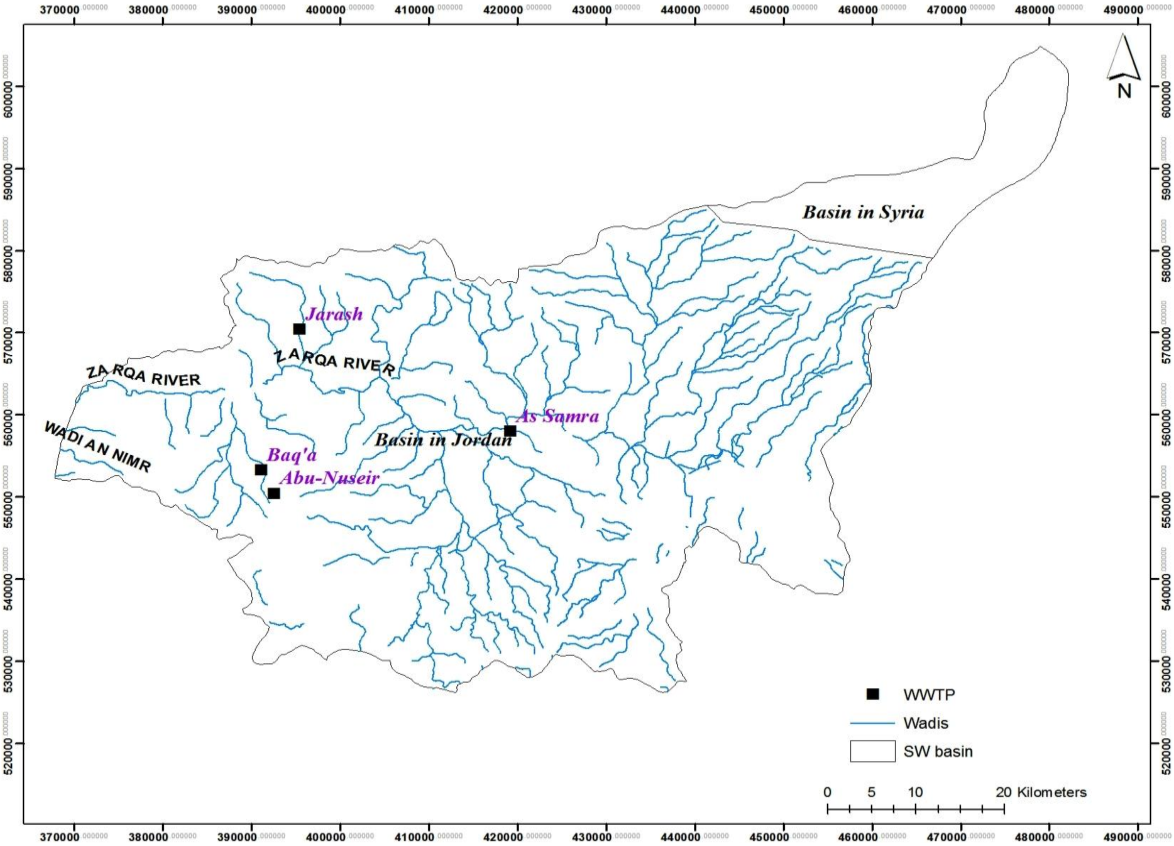


Figure 9: Wastewater treatment plants in the study area (MWI, open file2010).

In Amman Zarqa Basin, there are four wastewater treatment plants which discharge their effluents into the River. The other sources of inflow to the River are: rainfall runoff water and spring discharges.

The highly negative impacts of Khirbet As Samra's effluents were reflected on the River water quality. From 1985 till 2008 the As Samra Treatment Plant consisted of stabilization ponds. By the end of 2008, the plant was replaced by mechanical and chemical treatment plant producing a better effluent quality.

Khirbet As Samra new plant leads to improving conditions along the course of Zarqa River and in King Talal Dam. Further downstream, the water is channelled to the Jordan Valley where it mixes with water from King Abdullah Canal and is used for irrigating the land, especially in Deir Alla area.

5.1 Khirbet As Samra (KS) WSPs

As Samra wastewater stabilization ponds (WSPs) were constructed in 1985, with a design capacity of 68,000 m^3, and a detention time of 42 days. They were originally conceived as a temporary facility during the expansion and upgrading of the overloaded Ain Ghazal Treatment Plant (AGTP) at Amman.

KS treated the wastewater coming from Amman Zarqa, Ruseifa and Hashimiya areas. The system consisted of three parallel trains; each train had two anaerobic, four facultative and four maturation ponds, Figure (10). The areas and volumes of the individual ponds in each of the three units are given in Table (5).

Figure 10: Layout of Khirbet As Samra WSPs before its substitution by the new plant in 2008 (Google earth, 2010).

Table 5: Technical information of Khirbet As Samra stabilization ponds (MWI, open files).

Pond	Total depth (m)	Effective depth(m)	Unit area (ha)	Unit volume (m3)	Total volume (m3)
A1	5	3	3.17	95.100	285.300
A2	5	3	3.17	95.100	285.300
F1	2.25	1.5	7.25	108.75	326.250
F2	2	1.5	7.25	108.75	326.250
F3	2	1.5	7.25	108.75	326.250
F4	1.5	1.5	7.25	108.75	326.250
M1	1.5	1.25	6.25	78.125	234.375
M2	1.25	1.25	6.25	78.125	234.375
M3	1.25	1.25	6.25	78.125	234.375
M4	1.25	1.25	6.25	78.125	234.375
Total			60	937.7	2.813.100

The major components of As Samra WSPs system are:

- Head works (screen, grit removal units and septage receiving unit) at the abandoned Ain Gazal Treatment Plant AGTP.
- 40 kms long sewer – long siphon which conveyed the wastewater from AGTP site to Samra WSP.

- Zarqa pumping station which received the wastewater from Zarqa area and pumped it into the conveyance siphon running from AGTP to As Samra WSP.

Table 6: Original design parameters of Khirbet As Samra stabilization ponds.

Average Dry Weather Flow	**68.000 m3/ day**
Peak Wet Weather Flow	**148.000 m3/day**
Influent BOD5 concentration	**526 mg/L**
Influent BOD5 Loading	**35.750 kg/day**
Suspended Solids Loading	**42.0 g/day**

5.1.1 Performance of As Samra WSPs:

As Samra WSPs was put into service in 1985. The pond system began to receive flows in excess of design within two years from construction. Then the ponds began to be overloaded, where both hydraulic and organic loadings were much higher than the ponds design capacity. Other parameters such as TSS and COD were also very high at the inlet and accordingly at the outlet. However, the method of natural treatment is not recognized as suitable for dry, arid or semiarid regions (Bannayan, H, E. 1987).

The effluent from As Samra WSPs became highly loaded with organic and inorganic matter and nutrients. Therefore, As Samra was the reason of deterioration of the environment in the region. Further, this treatment system generated obnoxious odors and the WSP became a source of nuisance to the surrounding communities.

The designers of KS anticipated that further tertiary treatment would take place along Wadi Dhuleil, Zarqa River and King Talal Dam. When comparing pollution parameters of KS effluent with the flow in Wadi Dhuleil and Zarqa River, it can be

seen that there are some increases in these pollutants along the area (MWI, open files). Tables 43, 44, 45, 46, 48, 49, 50, 51 and 52 in the **Appendix (A)** show the effluent quality along the course of old plant operation.

The inflow amounts into Khirbet As Samra treatment plant is continuously increasing. It is also expected to keep increasing even when the other planned treatment projects are functioning. The Ministry of Water & Irrigation expects the plant to receive more than 142 MCM by 2025 (MWI 2001).

In the end of 2008, WSP was changed from a stabilization pond treatment plant to a mechanical and chemical treatment plant (Figure 10). The capacity of the new station is 268,000 m^3/d (MOE, 2008). The station serves 2.2 million people by treating an average of 200,000 m^3/d.

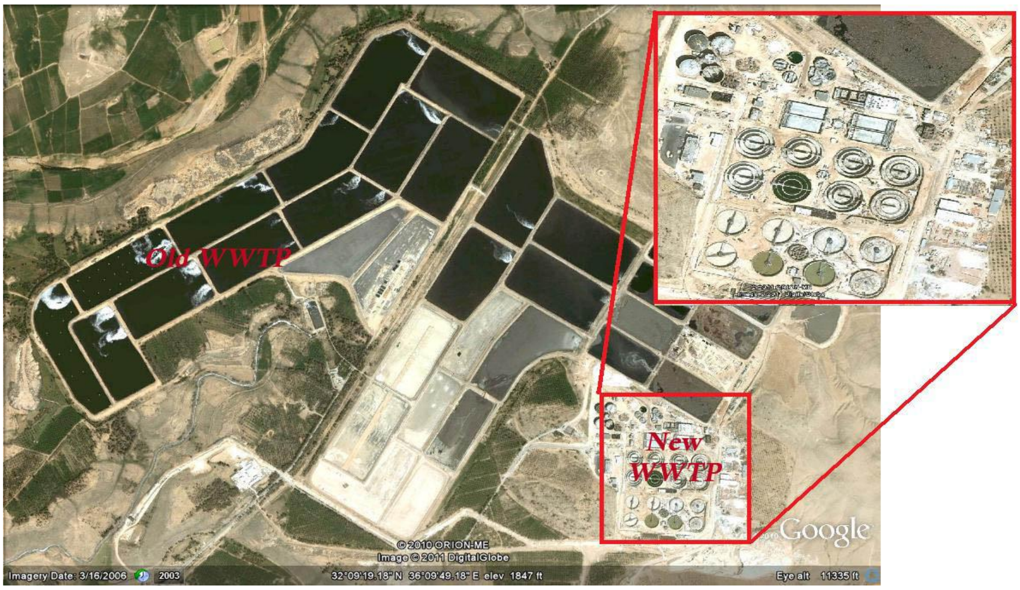


Figure 10: As Samra mechanical treatment.

5.2 Khirbet As Samra mechanical treatments

The incoming wastewater from Zarqa and Hashimiya pumping stations is distributed into two grit and two sulfide chambers:

- Each Grit Removal tank (19.6 * 13.0 m) has a volume of 1560 m^3 and an average hydraulic residence time (HRT) of 17 minutes. Air is introduced at the bottom of the grit chamber causing heavy particles to settle to be collected by a screw and discharged into the grit classifier. Air bubbles cause oil, grease and scum to float on the surface. It is then collected in a scum pit and pumped to the digesters.
- A Sulfide Removal tank consists of two aerated zones in series each of a capacity 1270 m^3. Ferric Chloride is injected as a catalyst for the sulfide removal. The settled water from the sulfide removal tanks is distributed into four primary settling tanks each is 83 m long and 20 m wide. These tanks remove about 65% of the total suspended solids and 40% of the BOD_5. Oil and grease are skimmed and collected in the scum chamber.

The settled water from the primary settling tanks is distributed into eight biological reactors each of a total volume of 26.200 m^3 consisting of three zones:

- Anoxic zone for exogenous denitrification (V =6875 m^3).
- Oxic zone where air is introduced continuously through air diffusers to remove BOD_5 and initiate nitrification (V=10.825 m^3).
- Endogenous zone where air is introduced intermittently for complete nitrification (V=8.500 m^3).

The effluent of the activated sludge process is distributed into eight secondary clarifiers each of a diameter of 54 m. Bio-suspended solids are separated and the settled sludge thickened and returned to the anoxic zone of the aeration tanks.

The clarified effluent of the secondary settling tanks flows to two plug flow chlorine contact basins each of a volume of 3.500 m^3, where it contacted with chlorine for about 35 minutes for its final disinfection to meet the Jordanian Standards 893/2006.

5.2.1 Characteristics and benefits of the new mechanical treatment

The major benefits of mechanical treatment in KS can be summarized as follows:

- Provides a proper wastewater treatment.
- Replaces an overload waste stabilization pond treatment system.
- Produces an effluent with a quality meeting the Jordanian Standards.
- Allows safe reuse of treated water for agriculture.
- Eliminates offensive odors in the surrounding area.
- Will develop the production of compost and fodder from digested sludge.
- Use the biogas produced in the sludge digesters to generate thermal and electrical power.
- Use the hydraulic potential energy at the inlet and outlet of the plant to produce electricity.

The actual plant design and construction is for the first stage until 2015, making provision for its expansion to the second phase until 2025 (Table 7 and 8).

Table 7: Design parameters in the different implementation phases.

Parameter	**Phase 1**	**Phase 2**
Population in Millions	2.27	3.3
Dry Weather Flow m^3/d	267.000	420.000

Table 8: Phase 1 effluent design parameters.

Item	Effluent water
BOD5	30 mg/l
TSS	30 mg/l
TN	30 mg/l
pH	6 - 9
DO	>2 mg/l

5.2.2 Sludge treatment

Primary sludge from the primary settling tanks is thickened in three covered circular thickeners each of diameter 23 m. Biological sludge from the aeration tanks is thickened in another three covered dissolved Air Flotation units (DAF) of a diameter of 17 m.

The two resulting sludge are mixed together in a covered tank of 80 m^3 volume before it is pumped to four anaerobic digesters each of capacity of 15.000 m^3.The sludge is kept in the digesters for three weeks at 35˚C where it is mixed thoroughly by Cannon Mixers using the recycled compressed biogas.

Heating of the recycled sludge is done by hot water recovered from the cooling of the engines in a shell-tube heat exchanger. The digested sludge flows to the digested sludge storage tank where it is pumped to 25 solar evaporation basins where it is dried to about 30 % dry solids.

5.2.3 Odor control

The plant is designed to ensure that no nuisance odor occurs at the boundaries of the treatment site. Odors are extracted in different places of the plant preventing the emission of unpleasant smells and providing satisfactory working conditions.

Polluted is treated in a scrubber system containing a special inert medium, the Biolite, in which naturally presented bacteria are fixed. Water is pulverized periodically on top of it absorbing the polluting gases.

The treated air in the lower part of the scrubber is collected and discharged to the atmosphere.

Table 9: Analysis of the effluent of the new As Samra treatment plant, 2008 (WAJ, open files).

Month 2 0 0 8	**pH**	**COD** mg/l	**BOD5** mg/l	**N-NH3** mg/l	**SS** mg/l	**N-NO3** mg/l	**N-NO2** mg/l	**TN** mg/l	**PO4** mg/l
Jan-2008	7.1	40.6	8.6	2.9	11.6	12.8	0.1	20.4	NA
Feb-2008	6.9	36.7	5.6	1.0	17.8	12.5	0.0	17.6	21.5
Mar-2008	6.9	49.0	5.8	1.0	19.2	13.6	0.2	19.4	23.6
Apr-2008	6.9	58.7	9.6	0.9	38.9	13.4	0.1	20.1	28.6
May-2008	6.9	43.7	6.8	1.4	18.8	17.3	0.1	23.7	NA
Jun-2008	7.0	36.0	5.9	1.0	12.3	16.1	0.1	20.6	NA
Jul-2008	7.0	29.0	4.3	0.9	5.8	14.3	0.1	18.5	NA
Aug-2008	7.1	34.1	5.5	1.3	8.1	15.4	0.1	22.2	NA
Sep-2008	7.3	36.5	5.3	2.0	9.3	11.9	0.3	19.3	NA
Oct-2008	7.2	41.0	5.0	1.0	9.1	15.8	0.1	21.0	NA
Nov-2008	7.2	56.7	7.9	3.4	12.4	11.5	0.8	20.7	NA
Dec-2008	7.1	46.7	7.2	2.9	9.2	11.9	1.8	20.3	NA
AV.	7.1	42.4	6.5	1.7	14.4	13.9	0.3	20.3	24.6

Table 10: Analysis of the effluent of the new As Samra treatment plant, 2009 (WAJ open files).

Month	pH	COD mg/l	BOD5 mg/l	N-NH3 mg/l	SS mg/l	N-NO3 mg/l	N-NO2 mg/l	TN mg/l	PO4 mg/l
Jan-2009	7.1	46.1	9.5	1.1	13.3	10.4	0.4	15.9	NA
Feb-2009	7.0	56.3	10.5	2.7	20.2	13.0	1.5	23.1	NA
Mar-2009	7.0	47.5	10.0	1.2	15.7	11.3	0.3	17.0	NA
Apr-2009	7.0	38.8	6.1	0.9	8.4	9.4	0.1	14.0	NA
May-2009	7.1	41.6	6.4	0.9	10.0	9.9	0.1	14.8	NA
Jun-2009	7.2	38.4	7.3	0.9	9.0	11.6	0.1	17.3	NA
Jul-2009	7.2	36.5	5.9	0.9	6.7	13.6	0.1	18.7	NA
Aug-2009	7.2	36.8	6.4	1.0	7.8	12.5	0.2	18.5	NA
Sep-2009	7.1	42.9	7.2	1.6	10.7	12.2	0.5	18.7	NA
Oct-2009	7.1	41.9	7	1.5	10.4	12.3	0.4	18.7	NA
Nov-2009	7.1	48.4	6.9	0.9	7.1	11.5	0.4	17.1	NA
Dec-2009	7	50	8.6	2.5	10.6	14.9	2.2	23.8	NA
AV.	**7.09**	**43.77**	**7.65**	**1.34**	**10.83**	**11.88**	**0.53**	**18.14**	**-**

Table 11: Analysis of the effluent of the new As Samra treatment plant, 2010 (WAJ, open files).

Month	pH	COD mg/l	BOD5 mg/l	N-NH3 mg/l	SS mg/l	N-NO3 mg/l	N-NO2 mg/l	TN mg/l	PO4 mg/l
Jan-2010	7.1	42.7	7.1	1.5	10.2	12.4	0.5	18.9	NA
Feb-2010	7.1	40.3	7.2	1.2	10.9	13.9	0.8	19.7	NA
Mar-2010	7.1	43.1	8.2	2.9	14	14.8	1.5	23.7	NA
Apr-2010	7.2	52.2	8.3	3.6	15.9	15	2.4	26.1	NA
May-2010	7.1	46.4	8.1	1.8	12.9	12.8	0.9	19.6	NA
Jun-2010	7.2	39.7	6.8	1.2	10.6	14	0.9	19.7	NA
Jul-2010	7.1	44.1	7.4	1.7	11.1	13.7	1	NA	NA
Aug-2010	7.2	38.9	6.7	1.3	10.2	14.1	0.8	20.2	NA
Sep-2010	7.24	50.16	8.13	1.10	11.27	14.84	0.76	20.99	NA
AV.	7.15	44.17	7.55	1.81	11.89	13.95	1.06	21.11	-

5.3 Efficiency and comparison

Tables (9, 10 and 11) illustrate the characteristic of the effluent water of KS mechanical treatment. The obtained data indicated that the average BOD concentration ranged from 6.5 to 7.5 mg/l, which is lower than the allowable Jordanian standards of 30 mg/l for wastewater discharges. Similar result for COD, NO_3, PO_4 and pH were also obtained. The KS mechanical treatment plant has high efficiency in respect to BOD, NH_4, NO_3, pH and COD removal.

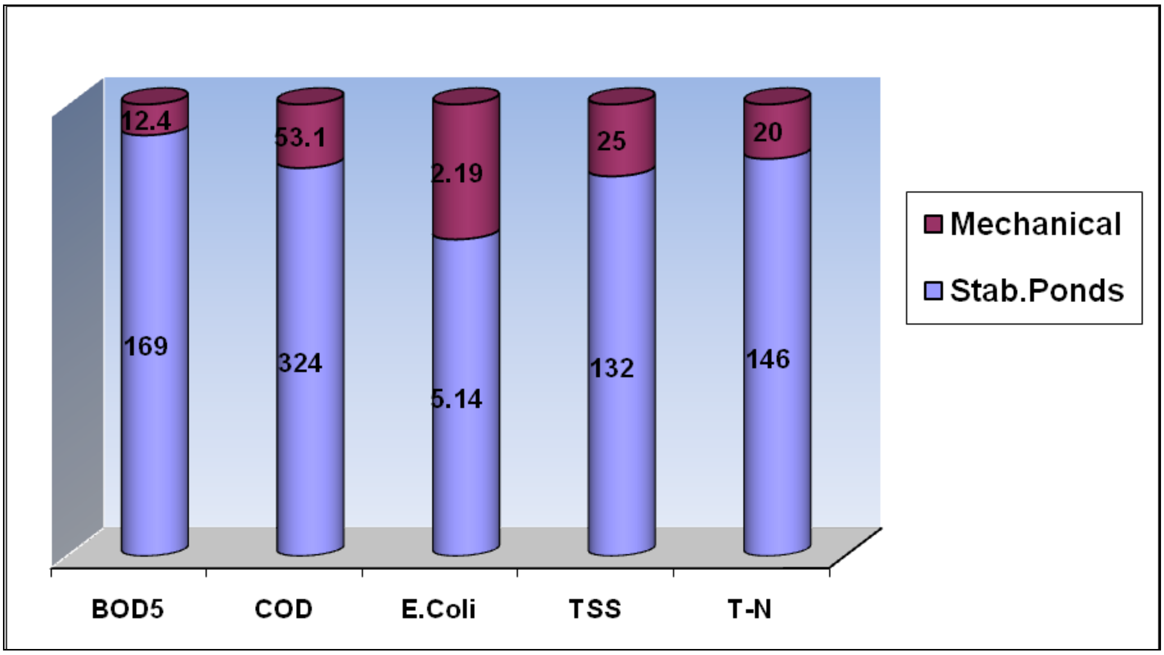


Figure 11: Comparison between the old treatment plant (stabilization ponds) and the new treatment plant (mechanical treatment).

In the effluent of the old KS tables 9, 10 and 11 the analyses indicated that the average BOD concentration was around 118.1 mg/l exceeding thus the Jordanian standards for effluent discharged. That concentration decreased along the river course as a result of biological decomposition and self – purification processes, but it remained far above the allowable standards limit. The COD reached 552 mg/l, an

unaccepted value for treated water. The plant has a low efficiency with regard to BOD_5, PO_4 and COD removal because it depend on natural treatment (stabilization ponds) affected by variations of climate parameters such as temperature, pressure and sunshine hours. The concentration of NH_4 should not be more than 15 mg/l according to the Jordanian standards, where the plant had not any facility for NH_4 removal. The effluent concentration of BOD in the year 2006 showed higher values than those of the previous years.

The obtained results indicated that the water quality in Zarqa River is affected strongly by treated systems of As Samra treatment plant.

6 Hydrochemistry

The main aim of this study is to evaluate the effect of improved wastewater treatment at KS on the recipient water bodies; Wadi Dhuleil, Zarqa River, King Talal Dam and the areas lying downstream of King Talal Dam. The total length of the river from the treatment plant to King Talal Dam (KTD) is about 46 km.

During the year of (2009 -2010), six sampling sites were chosen along Wadi Dhuleil and Zarqa River course from KS to Jarash Bridge, in addition to the samples which were taken from KTD, as shown in Figure (12).

Electric conductivity (EC), pH value, and temperature were measured directly on site using specialized digital equipment (WTW). Ca, Mg, Na, K, Cl, SO_4, PO_4, HCO_3, BOD_5, COD and NO_3 were determined in the laboratory according to Standard Method for Water and Wastewater Analyses and Deutsche EinheitsverFahren. The results are presented in the Tables (12, 13,14,15,16 and 17).

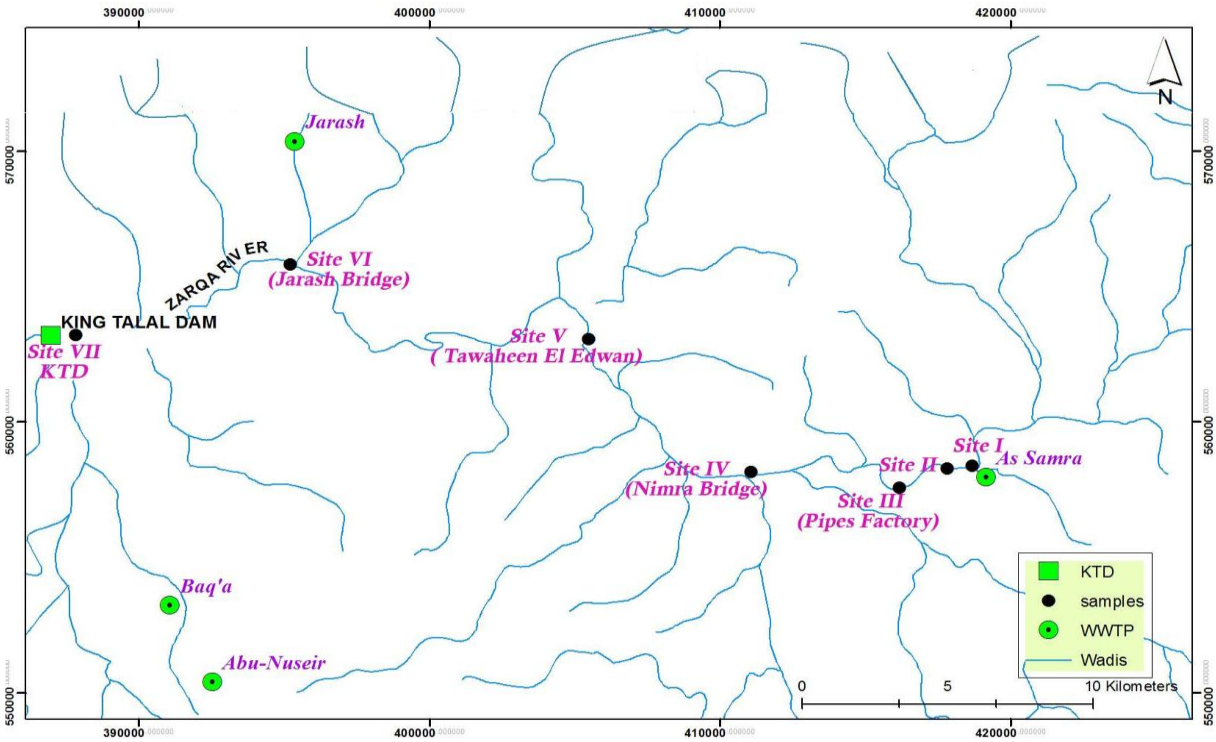


Figure 12: Location map of sampling sites along Zarqa River.

6.1 Chemical and Physical Parameters

The chemical and physical parameters were measured and analysed in seven sites along Wadi Dhuleil and Zarqa River to King Talal Dam. The first Site (I) represents the effluent of Khirbet As Samra water and lies down stream of the treatment plant Figure (13**),** Site II lies at a distance of 3.2 km downstream away from Site I. Site III; the Pipes Factory, lies 1.28 km downstream of Site II. Site IV, Nimra Bridge, lies 8.4 km downstream of Site III. Site V Tawaheen Al Edwan, lies 7.9 km downstream of Site IV. Site VI, Jarash Bridge, lies 19.280 km downstream of site V. Finally Site VII was located in King Talal Dam, the recipient body of Zarqa River Figure (13). It lies at a distance of around 5 km downstream of Jarash Bridge (Site VI).

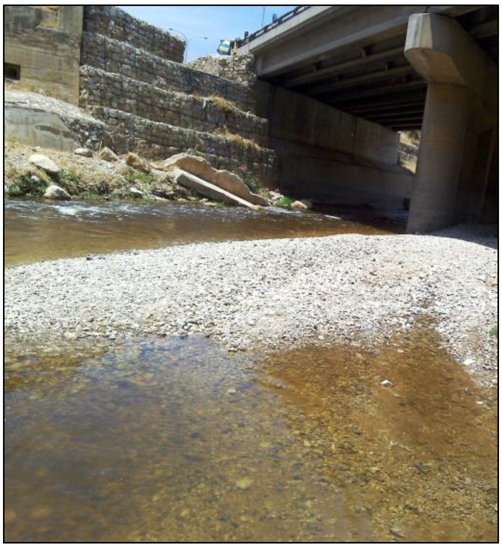
a.

b.

c.

d.

e.



f.

Figure 13: Sampling sites (a. Site I (outlet of KS), b. Site II, c. Site III (Pipe factory), d. Site IV (Nimra Bridge), e. Site V (Tawaheen El Edwan), f. Site VI (Jarash Bridge).

Figure 14: Sampling Site for Site VII (King Talal Dam).

Table 12: Chemical and physical analyses for Site I and II upstream of the Pipes Factory.

Samples2010	T ° C	pH	EC µs/cm	BOD5 mg/l	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	Cl meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Site 1- Jun	29	7.41	1920	5	9.5	4.6	1.112	3.8	5.9	1.98	0.33	10.9	0.061	126	1228.8
Aug- Site I	28.3	7.31	1951	11.4	10.42	5.6	1.34	2.2	5.7	1.76	0.43	11.4	0.049	100	1248.64
Oct – Site I	29.7	7.6	1900	5.3	8.348	4.9	1.78	3.9	7.5	0.7575	1.1	9.6	0.038	132	1216
Jun- Site II	27.2	7.9	1925	6.2	12.3	3.1	1.06	2.8	5.4	0.184	0.38	12.6	0.072	109	1232
Aug –Site II	29.6	7.82	1880	9	9.9	2.8	1.78	2.8	4.8	0.97	1.1	10.7	0.0114	82	1203.2
Site II - Oct	29.3	7.9	1947	7.8	9.7	5.4	1.65	2.6	6.2	1.32	0.97	10.8	0.039	N.A	1246.08

N.A: Not Analysed.

Table 13: Chemical and physical analyses of Wadi Dhuleil water at the (Pipes Factory) Site III.

Parameters	T°C	pH	EC µs/cm	BOD5 mg/l	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	Cl meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Aug 2009	28.4	7.41	1950	14.2	10.1	5.9	1.11	2.4	5.9	1.904	0.36	11.3	0.076	151	1248
Sep 2009	29.5	8.46	1914	15	10.1	6.7	0.97	1.4	5.8	2.53	0.38	10.3	0.081	107	1224.96
Oct 2009	26.9	7.54	2420	13.9	14.6	6.4	1.21	2	6.8	1.98	0.63	14.7	0.086	139	1548.8
Nov 2009	20.9	8.64	2890	15.1	15.1	7.5	1.32	3.8	9.8	1.94	0.415	15.3	0.074	155	1849.6
Dec 2009	19.7	8.74	3000	14.2	16.7	8.4	1.06	4.5	10.2	1.77	0.29	17.2	0.081	97	1920
Feb 2010	19	7.58	1800	15.2	8.3	5.1	0.98	3.6	6.2	2.15	0.299	8.9	0.068	130	1152
Mar 2010	20.9	7.31	1791	9.8	10.8	4.2	1.13	1.6	4.7	1.31	0.16	11.5	0.054	115	1146.24
Apr 2010	22.5	7.14	1875	5.9	9.9	4.6	0.81	2.8	4.8	2.61	0.126	11.2	0.063	150	1200
May 2010	26.8	8.04	2000	10	10.1	7.3	1.4	1.2	6.4	2.12	0.24	11.1	0.053	118	1280
Jun 2010	27.7	7.91	1923	4.8	10.2	4.9	1.11	3	5.8	1.98	0.36	11	0.078	181	1230.72
Jul 2010	29.5	8.31	2250	7.3	11.9	6.8	1.2	2.4	6.3	2.72	0.243	12.9	0.061	361	1440
Aug 2010	28.9	7.8	1978	19.2	10.61	5.9	0.98	2.2	5.9	2.13	0.64	10.9	0.052	155	1265.92
Sep 2010	29.2	7.84	1875	6.7	10.12	5	1.696	2	5.3	1.61	0.346	11.2	0.082	96	1200
Oct 2010	28.7	6.36	1947	N.A	10.9	5.6	1.2	1.8	6.2	1.15	0.46	11.5	0.079	83	1246.08

Table 14: Chemical and physical analyses for (Nimra Bridge) Site IV.

Parameters	T˚C	pH	EC µs/cm	BOD5 mg/l	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	Cl meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Aug 2009	27.4	8.28	2400	19.9	12.4	6.3	1.37	3.9	7.9	1.84	0.35	13.9	0.034	N.A	1536
Sep 2009	28	8.37	2500	25.7	13.3	6.5	1.38	3.8	8.1	2.14	0.33	14.3	0.0287	67	1600
Oct 2009	25.4	7.81	2300	11.9	12.2	6.4	0.98	3.5	7.9	1.83	0.21	13.1	0.026	82	1472
Nov 2009	20.4	7.62	1953	18.4	10.6	5.7	0.78	2.4	7.2	0.91	0.313	11	0.037	53	1249.92
Dec 2009	18	7.56	1772	16.5	9.6	4.8	1.12	2.5	6.7	0.84	0.23	9.9	0.034	40	1134.08
Feb 2010	18.6	7.75	1930	19.7	10.7	4.9	0.97	2.8	5.9	1.42	0.31	11.7	0.052	22	1235.2
Mar 2010	20.2	7.78	1993	12.9	10.5	5	1.1	3.2	6.4	1.9	0.39	11.1	0.079	33	1275.52
Apr 2010	21.2	7.25	2150	14	11.8	6.1	0.89	2.8	6.4	1.97	0.29	12.8	0.027	51	1376
May 2010	27.2	8.3	2190	19.1	10.9	6.7	1.71	2.6	7.9	1.98	0.28	11.7	0.034	61	1401.6
Jun 2010	28.3	8.26	2070	17.2	10.6	6.2	1.06	2.8	6.4	2.3	0.37	11.5	0.078	56	1324.8
Jul 2010	29.2	8.37	2060	9.2	12.6	3.9	1.1	3	5.5	1.69	0.369	13	0.031	31	1318.4
Aug 2010	27.9	8.32	2070	16.9	11.5	5.4	0.98	2.9	5.7	2.41	0.29	12.3	0.034	26	1324.8
Sep 2010	28.4	8.12	1984	8.1	11.8	5	1.01	2.03	5.9	1.17	0.185	12.5	0.043	36	1269.76
Oct 2010	26.3	8.22	2120	N.A	13	5.1	0.99	2.1	6.2	1.02	0.35	13.6	0.029	36	1356.8

Table 15: Chemical and physical analyses for (Tawaheen Al Edwan) Site V.

Parameters	T˚ C	pH	EC µs/cm	BOD5 mg/l	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	Cl meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Aug 2009	26.9	8.38	3090	13.7	13.9	9.7	1.87	4.3	11.7	2.34	0.45	14.8	0.096	96	1977.6
Sep 2009	27.1	8.41	2340	21.1	12.4	7.5	1.03	2.5	7.8	2.14	0.32	13.1	0.074	66	1497.6
Oct 2009	24.7	8.02	2470	15	12.9	7.9	1.23	2.6	8	1.97	0.33	14.2	0.081	64	1580.8
Nov 2009	17.5	8.11	2148	15.2	10.3	7.3	0.91	2.9	8.1	1.65	0.52	11.3	0.069	182	1374.72
Dec 2009	18.9	8.02	2230	9.8	11.2	5.2	0.909	4.8	7.4	2.42	0.18	12.3	0.061	55	1427.2
Feb 2010	18.7	7.68	2220	14.5	12.5	6.4	0.98	2.3	6.4	2.45	0.371	12.9	0.071	42	1420.8

Mar 2010	20.3	8.16	2270	11.1	12.7	5.7	1.1	3.2	7.2	1.79	0.369	13.2	0.056	20	1452.8
Apr 2010	20.7	7.6	2340	7.2	12.7	6.7	1.13	2.9	7.4	2.24	0.34	13.4	0.073	41	1497.6
May 2010	26	8.22	2490	13	12.7	7.2	1.8	3.2	8.2	2.16	0.35	13.6	0.085	34	1593.6
Jun 2010	27.2	8.2	2330	6.1	13.6	5.7	0.96	3	7.9	0.98	0.24	13.9	0.061	N.A	1491.2
Jul 2010	28	8.4	2270	9.2	12.7	6.8	1.03	2.1	7.2	1.69	0.229	13.4	0.062	N.A	1452.8
Aug 2010	27.1	8.42	2360	15.1	11.9	6.6	1.34	3.8	7.9	1.71	0.283	13.6	0.081	N.A	1510.4
Sep 2010	28.2	8.2	2250	5.5	12.1	6.5	1.23	2.8	7.7	1.63	0.23	12.9	0.0455	37	1440
Oct 2010	25.6	8.57	2370	N.A	12.13	7	1.7	2.8	7.8	2.03	0.48	13.3	0.076	N.A	1516.8

N.A: Not Analysed.

Table 16: Chemical and physical analyses for (Jarash Bridge) Site VI.

Parameters	**T° C**	**pH**	**EC µs/cm**	**BOD5 mg/l**	**Na meq/l**	**Ca meq/l**	**K meq/l**	**Mg meq/l**	**HCO3 meq/l**	**SO4 meq/l**	**NO3 meq/l**	**Cl meq/l**	**PO4 meq/l**	**COD mg/l**	**TDS mg/l**
Aug 2009	26.3	8.18	2380	15.4	12.5	6.5	1.26	3.5	7.8	2.12	0.24	13.4	0.068	29	1523.2
Sep 2009	27.5	8.42	2420	11.8	13.66	4.8	0.96	4.8	7.6	1.87	0.098	14.5	0.071	57.12	1548.8
Oct 2009	24.4	7.97	1969	10.7	10.2	5.2	1.06	3.1	6.9	1.25	0.18	11.3	0.063	56	1260.16
Nov 2009	14.1	7.86	2413	19.2	12.4	7.9	0.98	2.9	9.6	1.12	0.42	12.8	0.071	N.A	1544.32
Dec 2009	17	7.93	2450	10.6	12.1	7.8	1.32	3.2	8.4	2.05	0.57	13.4	0.072	88	1568
Feb 2010	16.3	7.57	2212	16.4	11.3	7.8	0.91	2.1	7.8	1.17	0.42	12.6	0.071	24	1415.68
Mar 2010	19.9	8.07	2210	12.3	12.1	6.4	0.91	2.6	7.3	1.8	0.314	12.7	0.034	52	1414.4
Apr 2010	20.1	7.63	2310	10.9	11.35	7.6	1.04	3.2	8.1	2.1	0.46	12.4	0.041	124	1478.4
May 2010	23.9	8.02	2390	11.5	11.4	6.5	2.3	3.6	8.7	1.7	0.24	12.3	0.031	749	1529.6
Jun 2010	27.9	8.41	2320	15.6	12.9	5.9	1.62	2.8	6.8	2.16	0.43	13.7	0.042	147	1484.8
Jul 2010	29.8	8.14	1917	18.1	10.8	5.2	1.1	2	5.4	1.78	0.36	11.4	0.0717	157	1226.88
Aug 2010	27.9	8.07	2420	20.4	12.9	7.1	1.21	2.9	7.9	2.11	0.21	13.9	0.072	148	1548.8
Sep 2010	27.5	8.02	2280	15.2	11.4	6.9	1.53	3.1	8.2	1.74	0.19	12.6	0.0153	80	1459.2
Oct 2010	26.3	8.08	2380	10.9	12.9	6.8	1.5	2.6	7.9	1.62	0.45	13.6	0.086	101	1523.2

Table 17: Chemical and physical analyses for (King Talal Dam) Site VII.

Date	T° C	EC µs/cm	pH	BOD5 mg/l	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	Cl meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Aug 2009	23	2030	7.46	14.6	11.8	3.8	0.91	3.7	6.4	0.98	0.23	12.7	0.064	66.2	1299.2
Oct 2009	24	1876	7.17	15.9	9	5.4	0.98	3.4	6.3	2.03	0.316	9.1	1.02	100.7	1200.64
Dec 2009	19.8	1250	5.68	10	6.6	3	0.62	2.2	3.8	1.13	0.32	6.95	0.48	N.A	800
Feb 2010	20.3	1551	8.54	10.8	6.3	4.6	1.3	3.1	5.2	1.7	0.41	6.6	1.63	47.1	992.64
Apr 2010	22.1	2110	7.49	15.1	9.09	6.2	1.24	4.2	6.9	2.95	0.65	9.4	1.36	140	1350.4
Jun 2010	24.9	1890	8	8.7	7.9	5.4	1.46	3.9	6.41	2.13	1.09	8.2	0.98	43	1209.6
Jul 2010	26.1	2330	7.82	16.1	11.57	6.86	0.8	4.12	7.78	1.92	1.08	11.7	0.83	31.58	1491.2
Aug 2010	24.6	2470	8.01	N.A	11.5	6.8	1.87	4.3	8.9	1.8	1.14	11.9	0.86	124.15	1580.8
Sep 2010	23.4	2490	7.56	N.A	11.8	6.8	1.23	4.37	9.2	1.26	1.33	12.3	0.71	97.5	1593.6

N.A: Not Analysed.

The old analyses conducted by Water Research and Study Centre (WRSC) of the University of Jordan in1989, 1990 and 199, in **Appendix B**.

6.1.1 Statistical Analyses

Statistical analyses are widely used in water analyses interpretation in order to summarize large volumes of data and create chemical relationships between the different constituents.

Tables (18, 19, 20, 21, 22 and 23) show the descriptive statistics (mean, maximum, minimum and standard deviation) for the sampling site.

Table 18: Descriptive statistic for the water parameters in Site I and II.

Parameters	Maximum	Minimum	Mean	Standard Deviation
T ˚ C	29.70	27.20	28.97	0.91
pH	7.90	7.31	7.66	0.26
EC µs/cm	1951.00	1880.00	1920.50	27.25
BOD5	11.40	5.00	7.45	2.46
Na meq/l	12.30	8.35	10.03	1.31
Ca meq/l	5.60	2.80	4.40	1.18
K meq/l	1.78	1.06	1.45	0.33
Mg meq/l	3.90	2.20	3.02	0.68
HCO3 meq/l	7.50	4.80	5.92	0.91
SO4 meq/l	1.98	0.18	1.16	0.66
NO3 meq/l	1.10	0.33	0.72	0.37
CL meq/l	12.60	9.60	11.00	0.98
PO4 meq/l	0.07	0.01	0.05	0.02
COD mg/l	132.00	82.00	109.80	20.15
TDS mg/l	1248.64	1203.20	1229.12	17.44

Table 19: Descriptive statistic for the water parameters in Site III.

Parameters	Maximum	Minimum	Mean	Standard Deviation
T˚C	29.5	19	25.61429	4.03
pH	8.74	6.36	7.79	0.64
EC	3000.00	1791.00	2115.21	390.19
BOD5	19.20	4.80	11.64	4.48
Na meq/l	16.70	8.30	11.39	2.38
Ca meq/l	8.40	4.20	6.02	1.22
K meq/l	1.70	0.81	1.16	0.22
Mg meq/l	4.50	1.20	2.48	0.96
HCO3 meq/l	10.20	4.70	6.44	1.62
SO4 meq/l	2.72	1.15	1.99	0.45
NO3 meq/l	0.64	0.13	0.35	0.15
CL meq/l	17.20	8.90	12.07	2.21
PO4 meq/l	0.09	0.05	0.07	0.01
COD mg/l	361.00	83.00	145.57	67.99
TDS mg/l	1920.00	1146.24	1353.74	249.72

Table 20: Descriptive statistic for the water parameters in Site IV.

Parameters	Maximum	Minimum	Mean	Standard Deviation
T°C	29.20	18.00	24.75	4.09
pH	8.37	7.25	8.00	0.36
EC µs/cm	2500.00	1772.00	2106.57	193.51
BOD5 mg/l	25.70	8.10	16.12	4.83
Na meq/l	13.30	9.60	11.54	1.09
Ca meq/l	6.70	3.90	5.57	0.82
K meq/l	1.71	0.78	1.10	0.24
Mg meq/l	3.90	2.03	2.88	0.57
HCO3 meq/l	8.10	5.50	6.72	0.91
SO4 meq/l	2.41	0.84	1.67	0.52
NO3 meq/l	0.39	0.19	0.30	0.06
Cl meq/l	14.30	9.90	12.31	1.24
PO4 meq/l	0.08	0.03	0.04	0.02
COD mg/l	82.00	22.00	45.69	17.66
TDS mg/l	1600.00	1134.08	1348.21	123.85

Table 21: Descriptive statistic for the water parameters in Site V.

Parameters	Maximum	Minimum	Mean	Standard Deviation
T° C	28.20	17.50	23.95	3.92
pH	8.57	7.60	8.14	0.28
EC µs/cm	3090.00	2148.00	2369.85	227.37
BOD5 mg/l	21.10	5.50	12.04	4.43
Na meq/l	13.90	10.30	12.43	0.90
Ca meq/l	9.70	5.20	6.86	1.10
K meq/l	1.87	0.91	1.19	0.33
Mg meq/l	4.80	2.10	3.11	0.75
HCO3 meq/l	11.70	6.40	7.92	1.19
SO4 meq/l	2.45	0.98	1.94	0.40
NO3 meq/l	0.52	0.18	0.32	0.10
Cl meq/l	14.80	11.30	13.28	0.83
PO4 meq/l	0.10	0.05	0.07	0.01
COD mg/l	182.00	20.00	63.70	46.68
TDS mg/l	1977.60	1374.72	1516.70	145.52

Table 22: Descriptive statistic for the water parameters in Site VI.

Parameters	Maximum	Minimum	Mean	Standard Deviation
T° C	29.80	14.10	23.28	5.30
pH	8.42	7.20	7.97	0.34
EC µs/cm	2450.00	1917.00	2283.92	169.57
BOD5 mg/l	20.40	10.60	14.47	3.79
Na meq/l	13.66	10.20	11.92	1.05
Ca meq/l	7.90	4.80	6.58	1.08
K meq/l	2.30	0.91	1.25	0.47
Mg meq/l	4.80	2.00	3.06	0.83
HCO3 meq/l	9.60	5.40	7.73	1.10
SO4 meq/l	2.16	1.12	1.77	0.36
NO3 meq/l	0.57	0.10	0.32	0.15
Cl meq/l	14.50	11.30	12.85	1.00
PO4 meq/l	0.09	0.02	0.06	0.02
COD mg/l	749.00	24.00	142.59	249.39
TDS mg/l	1568.00	1226.88	1461.71	108.53

Table 23: Descriptive statistic for the water parameters in Site VII.

Parameters	Maximum	Minimum	Mean	Standard Deviation
T° C	26.10	19.80	23.10	2.24
EC µs/cm	2470.00	1250.00	1938.38	397.13
pH	8.54	5.68	7.52	0.85
BOD5 mg/l	16.10	8.70	13.03	3.09
Na meq/l	11.80	6.30	9.22	2.22
Ca meq/l	6.86	3.00	5.26	1.39
K meq/l	1.87	0.62	1.15	0.40
Mg meq/l	4.30	2.20	3.62	0.70
HCO3 meq/l	8.90	3.80	6.46	1.54
SO4 meq/l	2.95	0.98	1.83	0.61
NO3 meq/l	1.14	0.23	0.65	0.39
Cl meq/l	12.70	6.60	9.57	2.32
PO4 meq/l	1.63	0.06	0.90	0.49
COD mg/l	140.00	31.58	78.96	42.73
TDS mg/l	1580.80	800.00	1240.56	254.16

6.1.2 Temperature (˚ C)

The temperature of the water samples ranged from 25.4 to14.1˚C in autumn, 26 to 20.2 ˚C in spring, 27.2 to 31.8 ˚C in summer and during winter from16.3 to 18.7 ˚ C. Generally, an increase in temperature along the Zarqa River was observed in spring and summer as shown in figure (15).

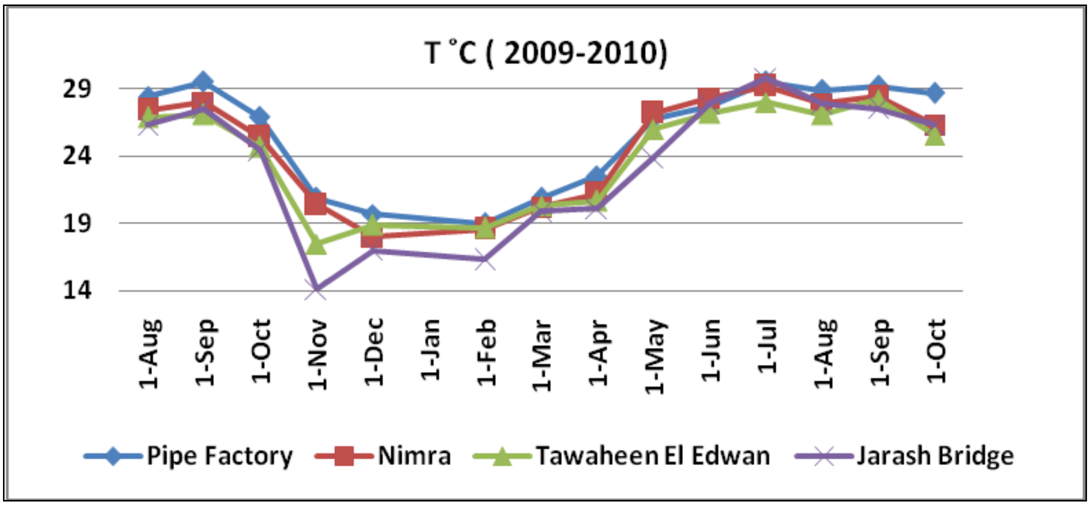


Figure 15: Sampling temperature during observation period.

The lowest temperature values were recorded during winter and autumn, while the highest were during the summer and spring period. Higher water temperature can reduce the dissolved oxygen concentrations in water and thus its availability to aquatic organisms.

6.1.3 pH

The pH value of the water affects the solubility and the bioavailability of substances. Figure (16) shows the slight fluctuations of pH values of KS effluents ranging from 7 to 7.24 when discharging into the recipient water body. The mean value of the pH in the effluents before the new WWTP, in the old stabilization pond system, was around 8.

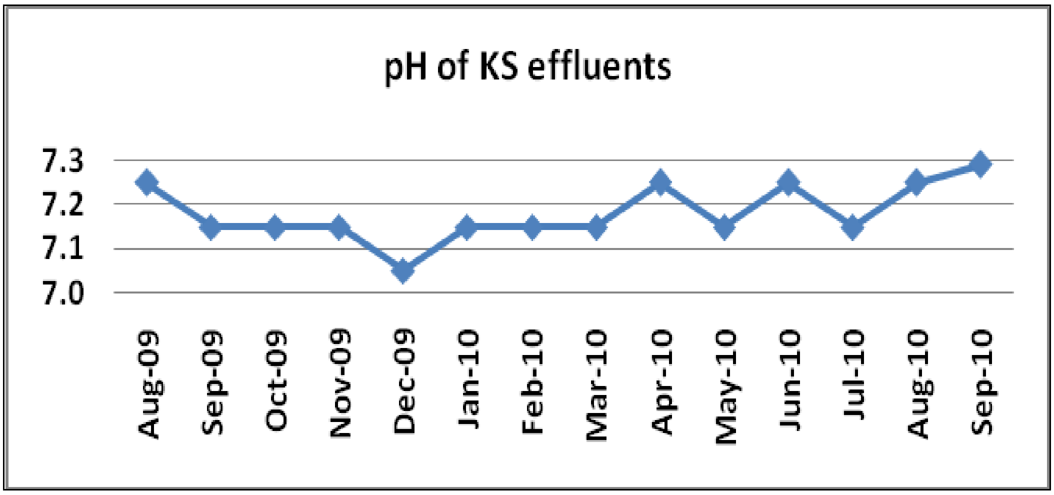


Figure 16: Fluctuations of pH effluents during observation period.

The pH values of all the collected samples along the River course during the observation period varied from 7.41 to 8.46 in summer, 6.46 to 8.47 in autumn, 7.57 to 7.75 in winter and 7.14 to 8.3 during spring. Along the River course, slight increase is taken place in the pH values due to a result of algal activity.

Figure (17) shows the pH level along the flow course. The fluctuations are mainly caused by changes in the bicarbonate concentration; the high pH was caused by the uptake of CO_2 by algae during photosynthesis.

In the old treatment plant effluent and along the Zarqa River course, the pH values ranged from 7 to 8.4 in summer, 6.9 to 8.57 in autumn, 6.78 to 8.24 in winter and from 7.38 to 8.82 in spring time. There are accordingly two major changes in pH values between the effluents of the old treatment plant and the new one. That also applied to the course of Zarqa River.

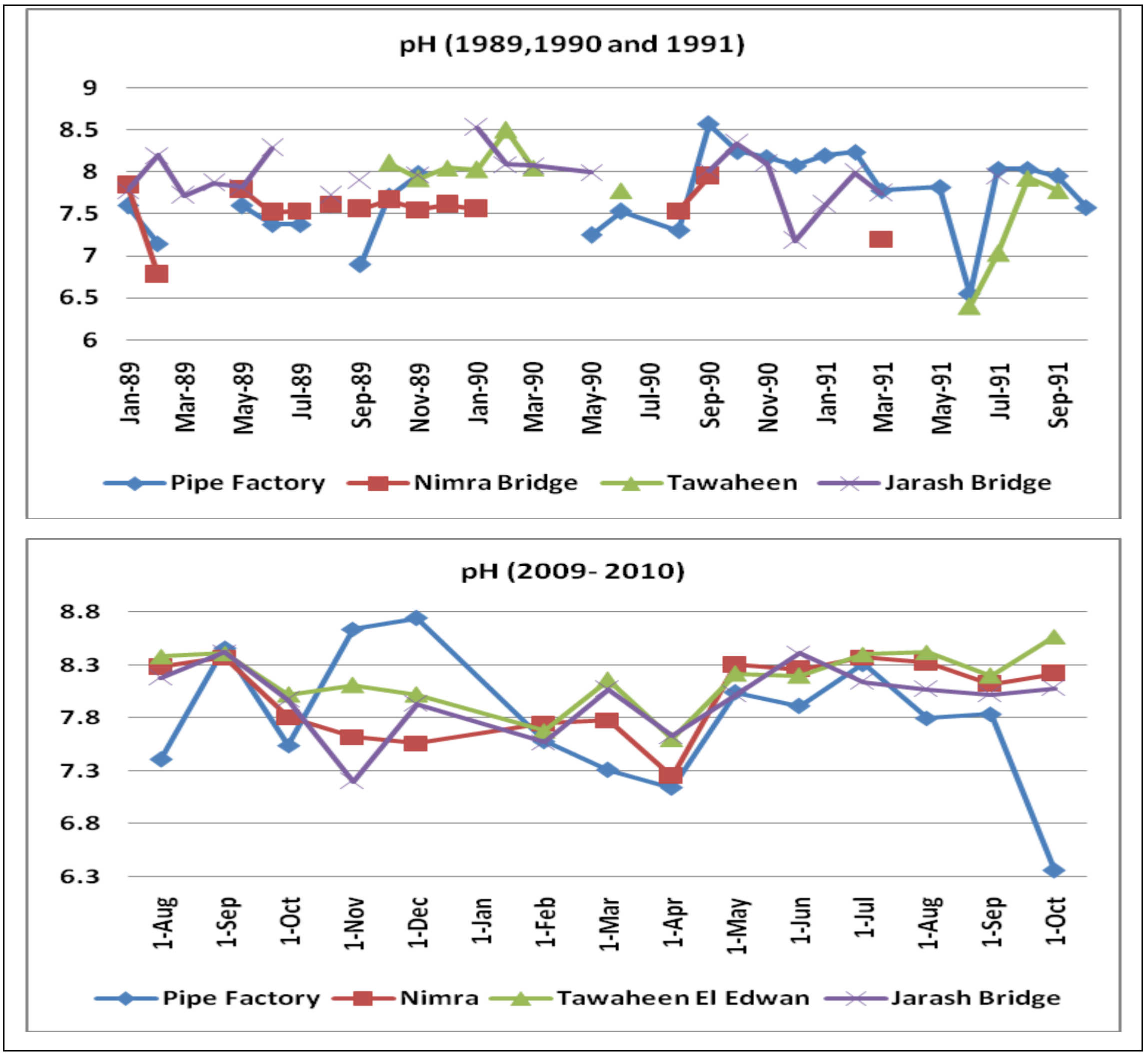


Figure 17: The pH-values during the observation period, compared with old analysis along the River course.

In KTD, the minimum value for pH measured was 5.68, whereas, the maximum value of 8.54 was obtained in February 2010 as represented in Figure (18). This indicates that the increasing pH is mainly caused by the increasing of bicarbonate concentration.

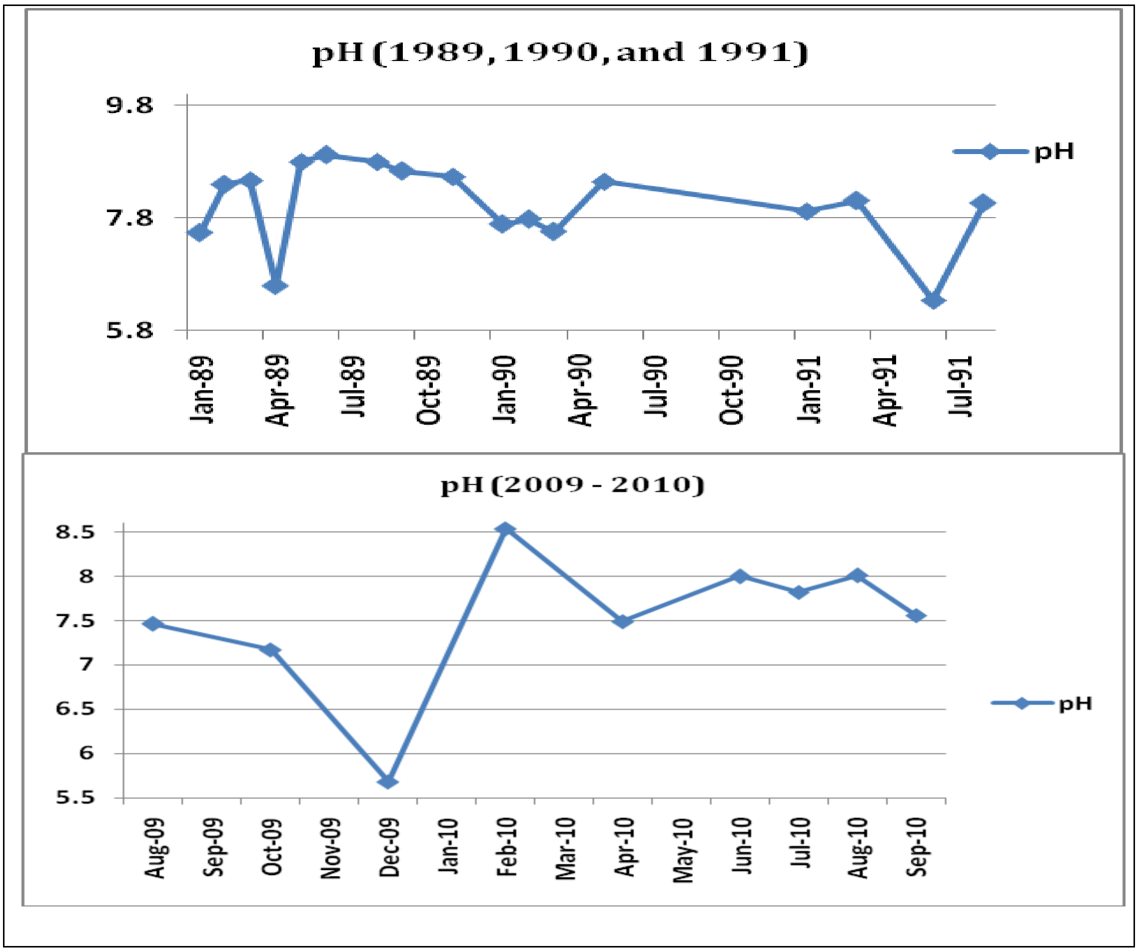


Figure 18: The pH-values in King Talal Dam during observation period and in the old analyse.

While the pH values for KTD in 1989, 1990 and 1991 were in the range of 6.34 to 8.92, it decreased slightly in recent years.

6.1.4 Electrical Conductivity (EC µs/cm)

The electrical conductivity of water is a useful indicator of its salinity or total salts content. Figure (19) shows the EC of the different sites for the observation period, which ranged from 1772 to 3090µS/cm. Generally a rapid increase in Pipe Factory sampling site during winter was observed.

As a result of the elimination of the stabilization ponds with their huge area and accordingly large evaporation a mounts, the salts content of recent plant effluent

decreased dramatically from an a average of about 2800 µS/cm (Table 44) to about 1920 µS/cm (Table 18).

This decrease in salinity has its positive impacts on Zarqa River water and irrigated land along its course, on KTD reservoir water quality and on the quality of irrigation water in the JV area, and hence on the crop production and its quality.

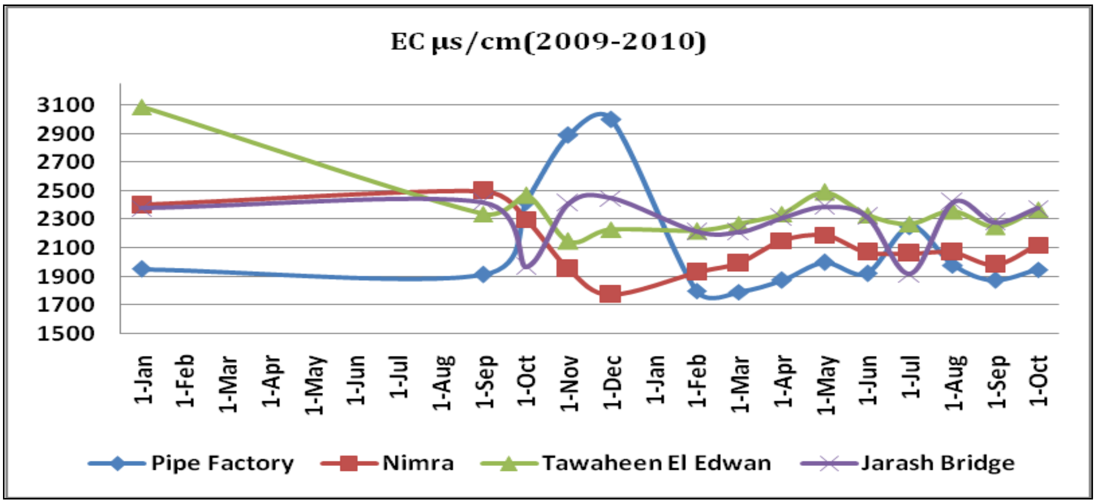


Figure 19: Electrical conductivity (EC µS/cm) at the sampling sites.

The EC values of Site I ranged from 1900 to 1951µS/cm. Generally, a small dropping in the EC value in Site II takes place. It ranged from 1880 to 1947µS/cm. seemingly as a result of fresh water seepages entering the system. In the Pipe Factory testing site III the EC ranged from 1791 to3000µS/cm, 1772 to 2500µS/cm in Nimra Bridge site, 2148 to 3090µS/cm in Tawaheen El Edwan and 1917 to 2450µS/cm in Jarash Bridge testing site. The results of EC values during the years1989, 1990 and1991 which ranged from 2140 to 3420µS/cm in testing site III, 1485 to2000µS/cm in Site IV, 2200 to3900µS/cm in Site V and 1100 to 2790 µS/cm in Site VI. This indicates that no major changes have taken place in the salinity of the effluents of KS along Zarqa River course. Figure (20) shows the fluctuation of EC vales in KTD.

The changes increase or decreases in the salinity of the Zarqa River its course reflect the effects of rainwater (floods) and the discharges of groundwater seepages as

springs. Local small source of farming and industrial waste water are also observed along Zarqa River, which contributes to its fluctuating salinity (EC) pollutants contents.

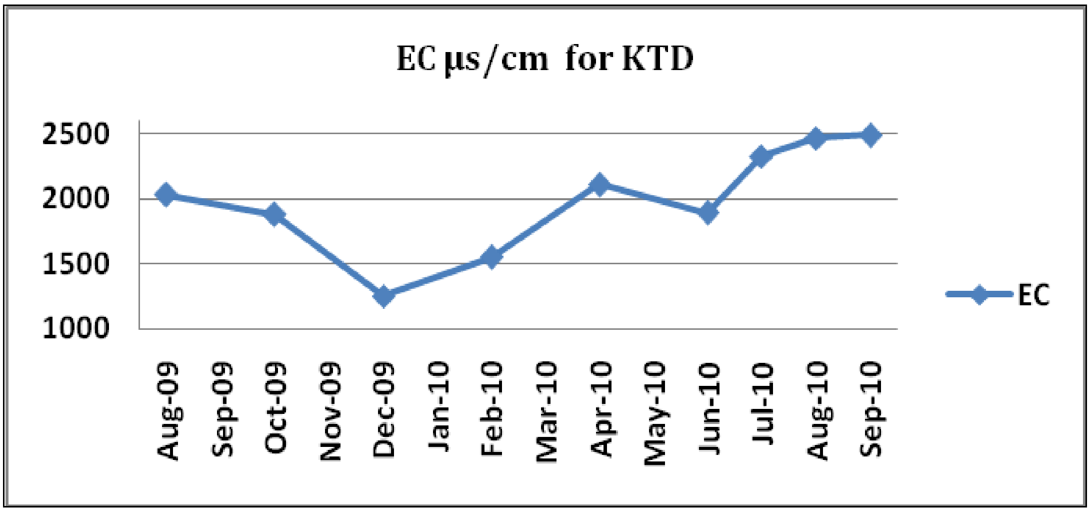


Figure 20: Fluctuations of EC values in KTD during observation period.

The old analyses of KTD during the years of 1989, 1990 and 1991 show EC values in a range of 1256 to 2560µS/cm. This might indicate at improvements of the water quality in King Talal Dam as affected by the improvement of Khirbet As Samra treatment, but it also can be the result of flood flows.

6.1.5 TDS (mg/l)

A general indication of the chemical water quality is obtained from the total dissolved solids. TDS values were calculated mathematically according to the following equations:

TDS mg/l = EC µs/cm * 0.64

The TDS values in the tables therefore are reflected in the EC values and the same interpretation of the EC values is valid for the TDS values.

6.1.6 Sodium (Na+)

Sodium is a very reactive metal, and does not occur in free form in nature. Figure (21) shows the Na^+ concentration during the observation period ranged from 6.3 to 16.7meq/l along the river course. Despite it were around 3.29 to 17.3meq/l in past years. Slight decreasing along the river indicated the dilution effect by fresh surface and groundwater along the river course.

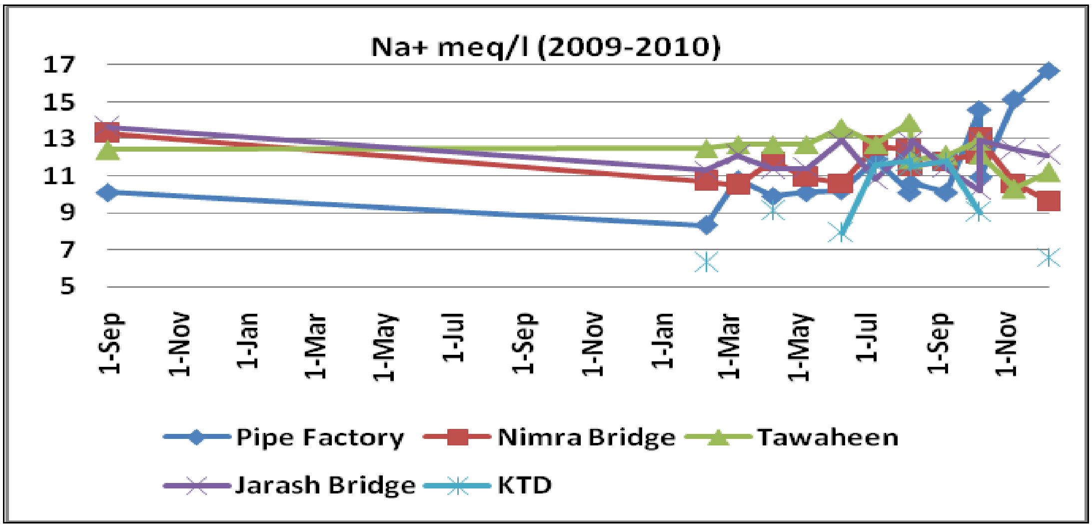


Figure 21: Sodium concentrations sampling sites.

Generally, the treated water content of Na^+ doesn't show clear decreasing or increasing trends throughout the course. Na^+ is a conservative chemical in surface water, but if the water is in contact with clays ion exchange might take place.

6.1.7 Calcium (Ca^{+2})

Calcium ions are common minerals in ground and surface water. They may result from the leaching of soil, rocks and other sources. The concentration of Calcium increases along the river; but in winter, the increase is very small. Figure (22) shows the Ca^{+2} concentrations in 1989, 1990 and 1991 that ranged from 2.5 to 11.3 meq/l, while it ranged from 2.8 to 13.9 meq/l during observation period.

The increase along the river course is attributed to reactions of the water with the carbonates of the riverbed. The obtained results shown a decreasing trend throughout the river course, compared with the old analyses.

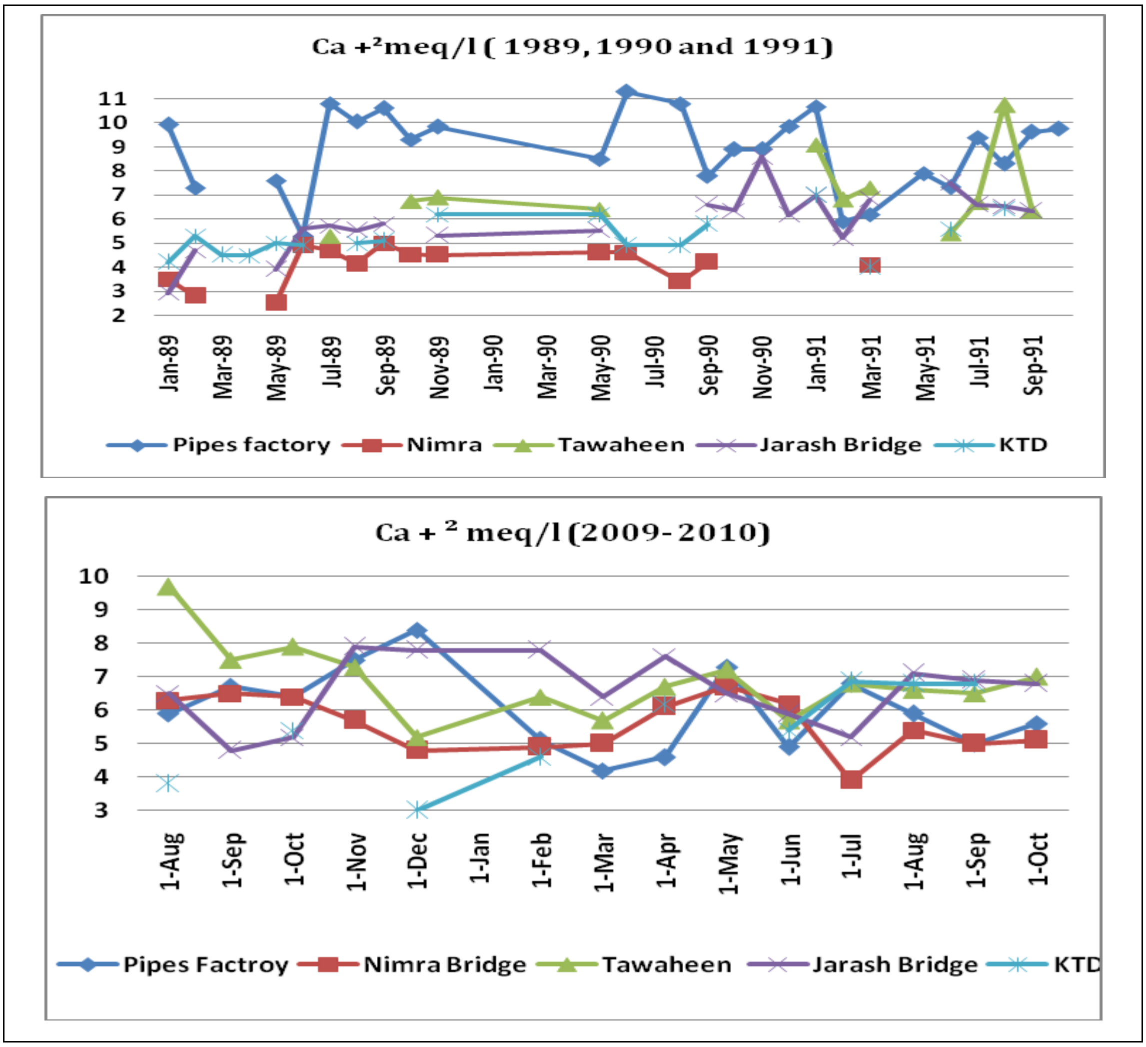


Figure 22: Calcium concentrations in the sampling sites during the observation period, and in the old analyses.

In the effluent of the old treatment plant higher BOD_5 and COD contents were found than in the new treatment plant effluents. The self-purification of the river had hence caused higher amount of BOD_5 and COD to oxidize producing more CO_2 and eventually SO_4^-, in turn reacting with the river bed rocks of carbonates, releasing here-with additional of calcium and magnesium ions.

6.1.8 Magnesium (Mg^{+2})

The Mg concentration shows an unstable pattern of fluctuations indicating the effect of flood waters with low Mg concentration along the river course having Mg^{+2} concentrations of 1.2 to 4.8meq/l. It ranged from 1.2 to 9.8meq/l in the old treatment plant effluents. Figure (23) shows the slight decreases in the magnesium concentration of the water along the river compared with the old treatment effluent water has the same resound as explained above for the decrease in the calcium concentration.

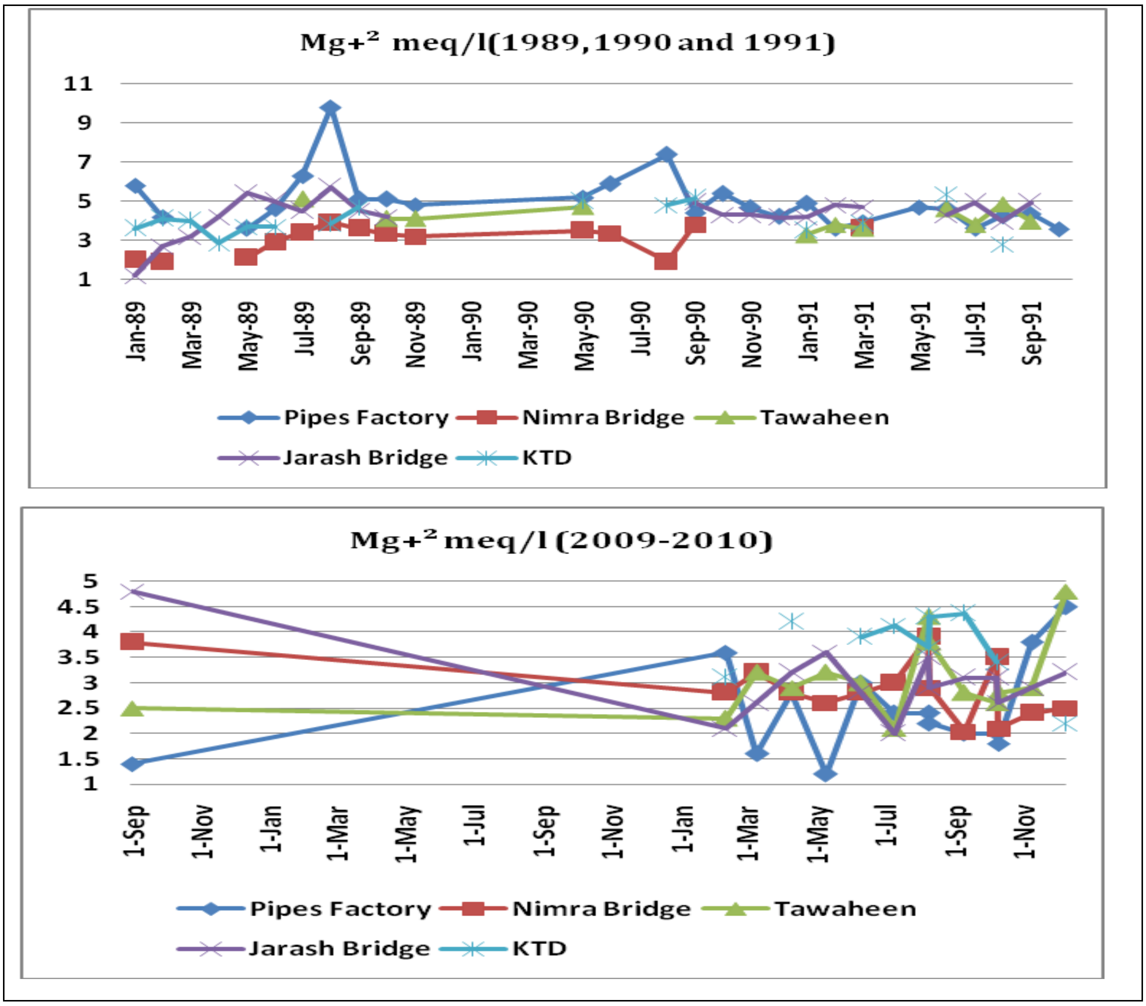


Figure 23: Magnesium concentrations in the sampling sites during the observation period, and in the old analyses.

6.1.9 Potassium (K^+)

The Potassium concentrations along the river course are shown in Figure (24). It ranged from 0.62 to 2.3 meq/l in the recent analyses, while it ranged from 0.11 to 2.68 meq/l in old analyses.

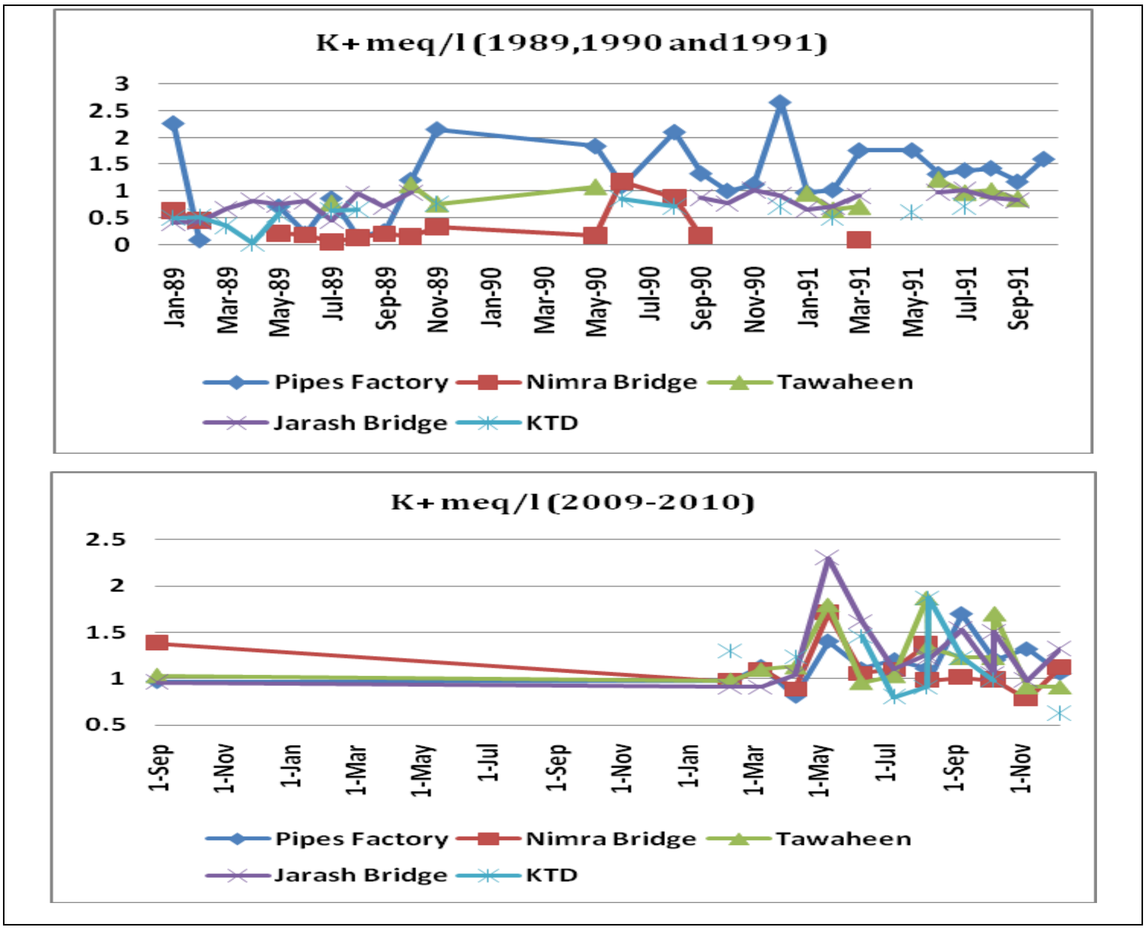


Figure 24: Potassium concentrations in the sampling sites during the observation period, and in the old analyses.

6.1.10 Chloride (Cl^-)

All chloride salts are highly soluble. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$).

The data given in the table's for new KS show that the minimum value of Cl^- for Site I was 9.6 meq/l, while the maximum concentration was 11.4 meq/l. And it ranged from 10.7 to 12.6 meq/l in Site II, and in the other sites from 8.9 to 17.2 meq/l. There

are no clear changes in the Cl^- concentrations between the effluents of the old and new treatment plants, as represented in Figure (25).

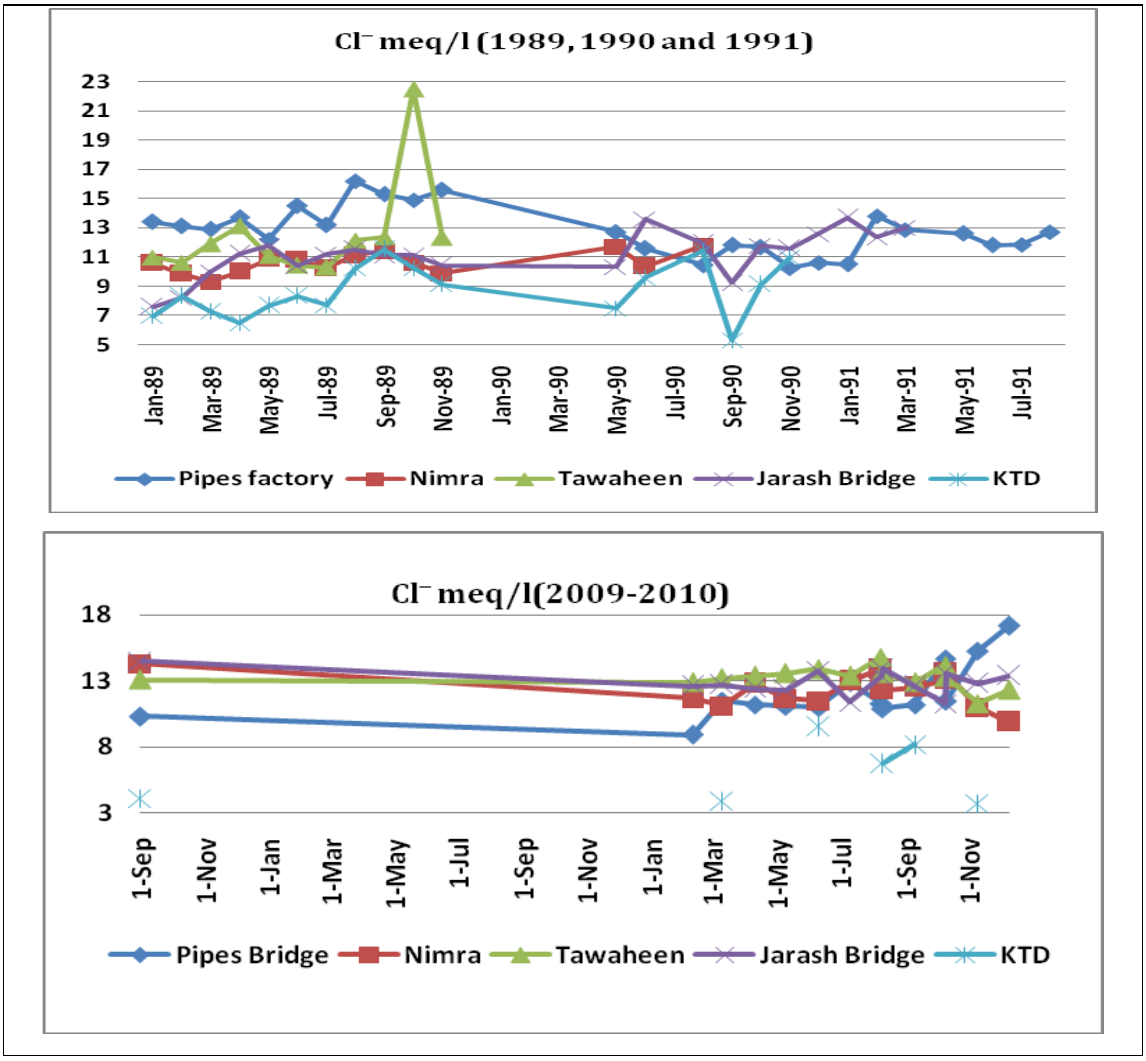


Figure 25: Chloride concentration in the sampling sites during the observation period, and in the old analyses.

6.1.11 Phosphate (PO_4^{-3})

Soluble phosphate is an important nutrient for plants including bacteria and algae, and a limiting factor for aquatic growth. The PO_4^{-3} concentration shows a decreasing pattern from KS downstream to Jarash Bridge. It ranged from 0.01 to 0.1meq/l along the river course. The effluent of KS has an average PO_4^{-3} concentration of 0.25meq/l, while; Jarash Bridge it has a value 0.055 meq/l. The decrease in the concentration along the river course indicates the phosphate uptake by aquatic plants.

In Figure (26) the high concentration of PO_4^{-3} in king Talal Dam reaches maximum values in spring and summer times and ranged from 0.06 to 0.19 to 1.63 meq/l, contributing to its high eutrophication process.

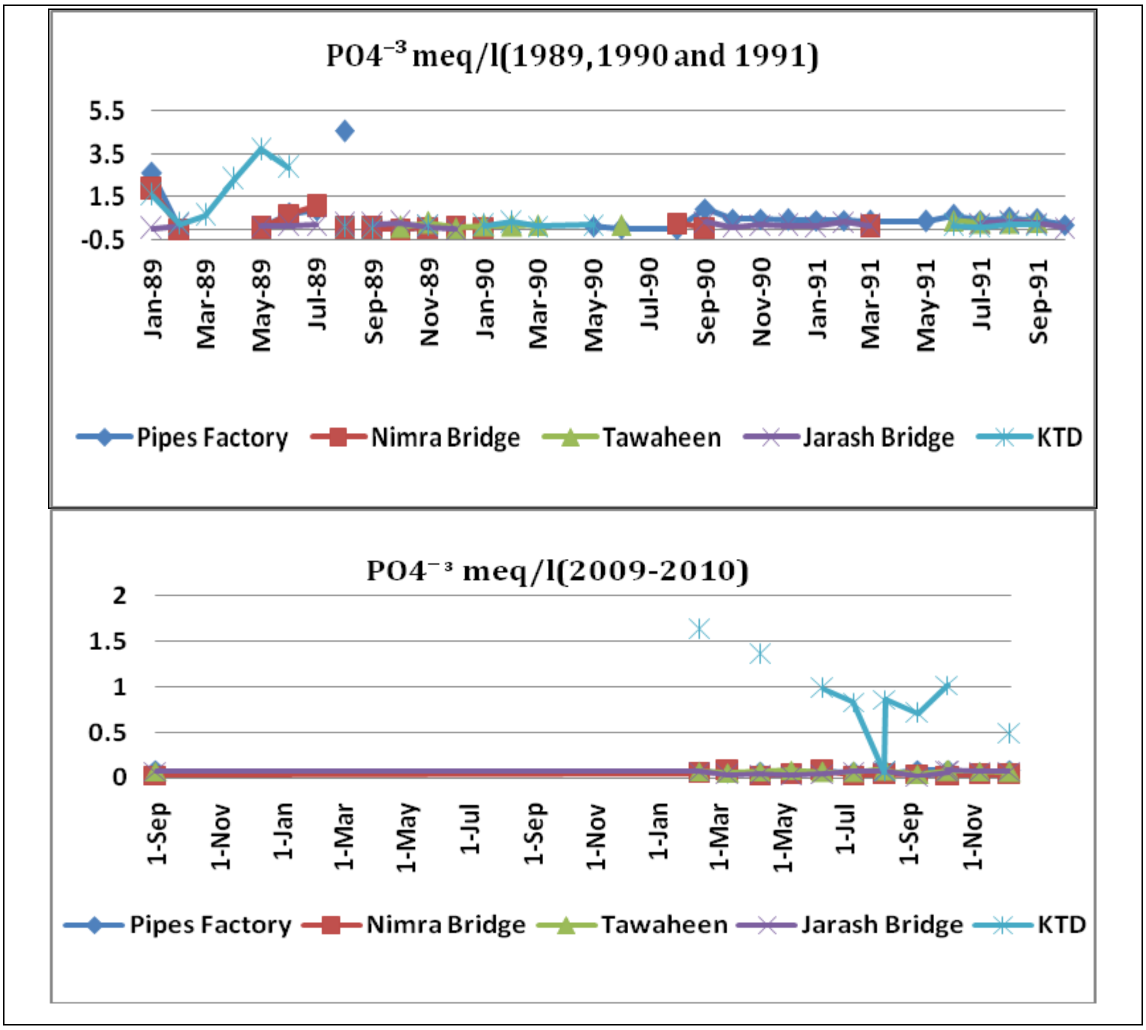


Figure 26: Phosphate concentration in the sampling sites during the observation period, and in the old analyses.

On comparing the present PO_4^{-3} level along the river course with that of effluents of the old treatment plant one finds a large decrease along river course in KTD.

6.1.12 Nitrate ($NO3^{-}$)

The Nitrate concentration of KS effluent is very low (few mg/l). Figure (27) shows the increased NO_3 concentration along the river course gradually to a concentration ranging from 0.1 to 1.10 meq/l, while the concentration in the effluents of the old treatment plant ranged from 0.24 to 2.24 meq/l.

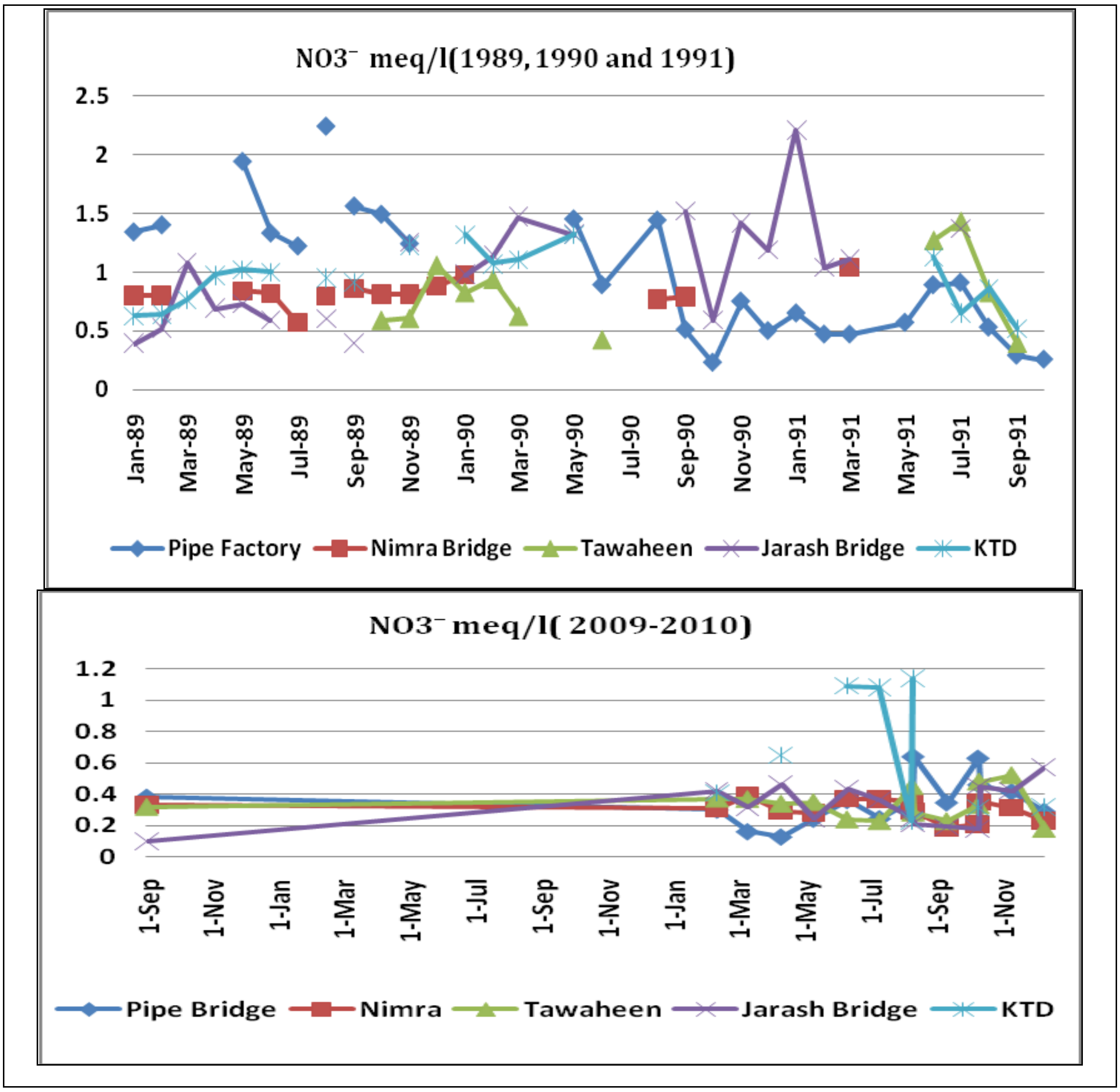


Figure 27: Nitrate concentrations in the sampling sites during the observation period, and in the old analyses.

The low concentration of soluble nitrate in KS effluent is indicative of a well functioning anaerobic (anoxic) biodegradation (denitrification), nitrate uptake by algae with downstream flow and with more oxygenation of the water. More nitrates are formed as a result of increased microbial oxidation of ammonium (nitrification). The NO_3 concentration increases in KTD and range from 0.23 to 1.14 meq/l. This increase is caused by the continuous action of nitrification processes.

6.1.13 Sulfate (SO_4^{-2})

The SO_4 content decreases rapidly along the river course, as shown in Figure (28) whereas it ranges from about 0.18 to 2.72 meq/l in the effluent of KS, the concentration in Jarash Bridge decreases to around 2.16 to 1.12 meq/l.

The concentration in the KTD water ranges from 0.98 to 1.83 meq/l. Aerobic decomposition and oxidative processes caused by micro-organisms in the dam contribute to the SO_4^{-2}concentration of water.

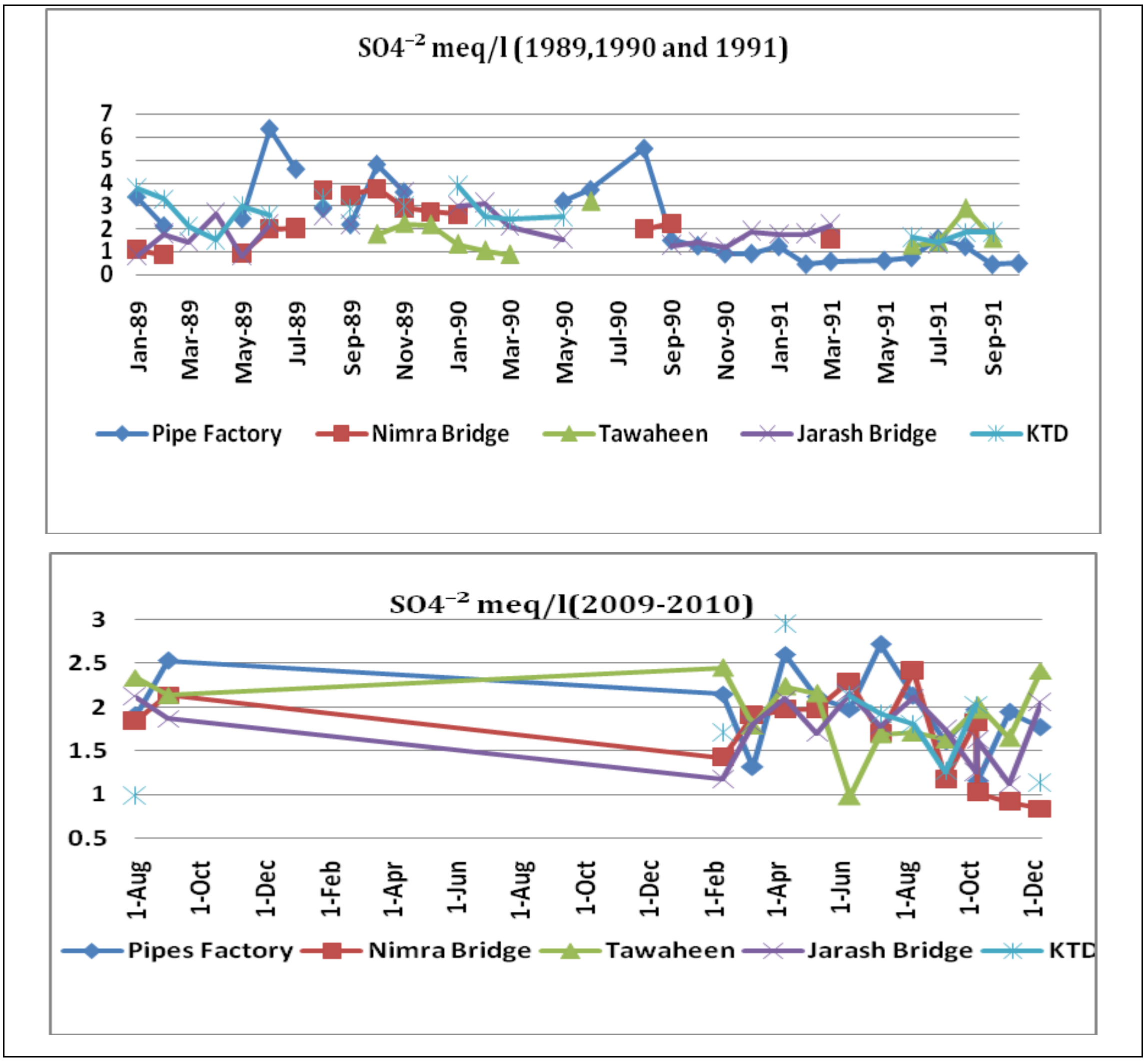


Figure 28: Sulfate concentrations in sampling test site during observation period, and comparing with old analysis.

6.1.14 Bicarbonate (HCO_3^-)

The HCO_3^- concentration along the river course reaches a maximum value around 11.7 meq/l in Site V and the minimum values in Site VII around 4 meq/l.

The bicarbonate values in (1989, 1990 and 19991) ranging from between 1.36 to16.32 meq/l. The production of H_2S due to anaerobic processes allows the CO_2 gas to escape that result in lowering the HCO_3 content of the water along river.

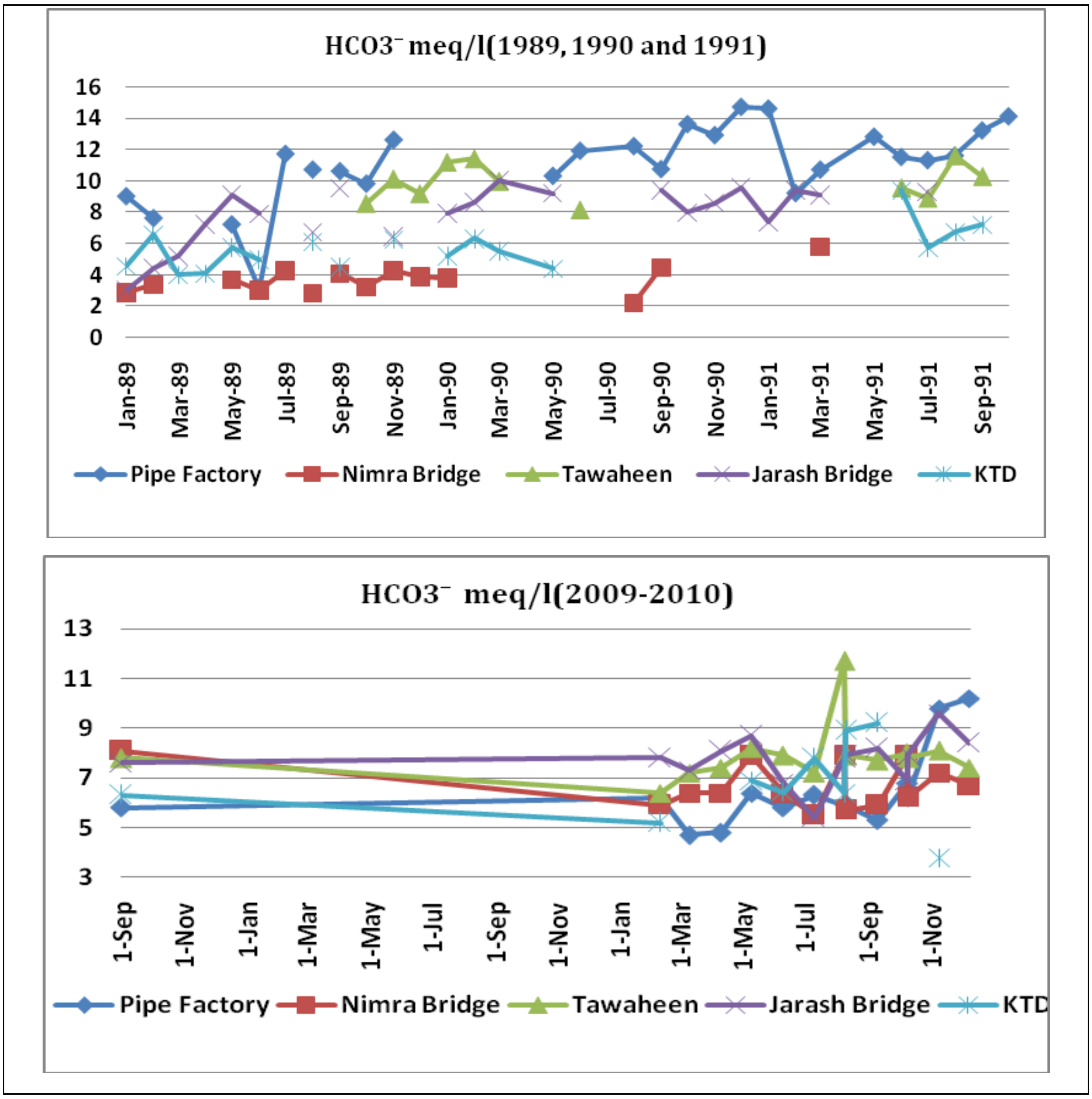


Figure 29: Bicarbonate concentrations in the sampling sites during the observation period, and in the old analyses.

6.1.15 Trace Elements

The trace elements Pb, Mn, Co and Cu analyzed in water samples and were found to have very low concentrations of less than 0.01 ppm, Table (24) shows the trace elements concentrations. Fe the main trace element can be found in small concentration of 0.02 ppm.

Table 24: The trace elements concentrations in the sampling sites along the river course.

Oct- 2009	Fe(ppm)	Cu (ppm)	Pb (ppm)	Mn(ppm)	Co (ppm)
Site I	0.01	<0.01	<0.01	<0.01	<0.01
Site II	0.01	<0.01	<0.01	<0.01	<0.01
Site III	0.02	<0.01	<0.01	<0.01	<0.01
Site IV	0.01	0.01	<0.01	<0.01	<0.01
Site V	0.01	0.01	<0.01	<0.01	<0.01
Site VI	0.01	0.01	<0.01	<0.01	<0.01
Site VII	0.02	0.01	<0.01	<0.01	<0.01

6.2 Biological parameters

6.2.1 Chemical Oxygen Demand (COD mg/l)

COD test is used to measure the content of the organic and inorganic matter in water. Figure (30) shows the efficiency of KS new WWTP.

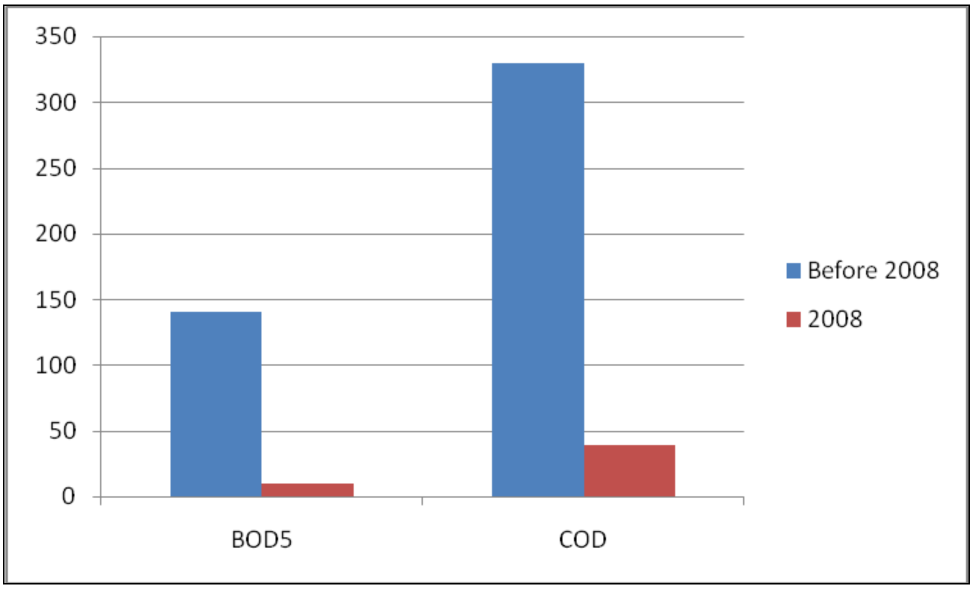


Figure 30: The BOD_5 and COD values before and after KS new WWTP.

The values of COD in Khirbet As Samra WWTP effluent is shown in Figure (31). There is an increase in the values which ranged from 100 to 132 mg/l in site I. The concentration of COD decreased in site II and ranged from 82 to109 mg/l respectively.

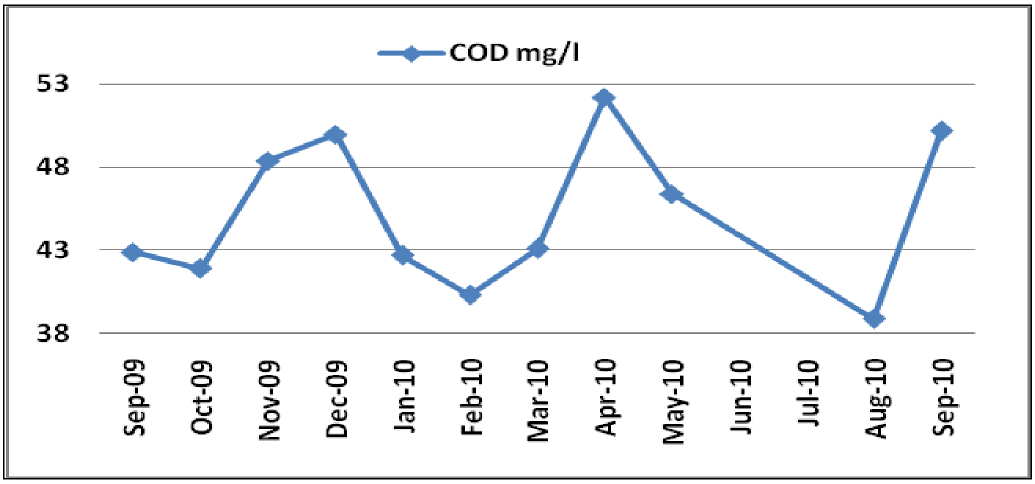


Figure 31: Fluctuations of COD values in KS effluents during the observation period.

In the recent analyses the COD value ranged from 36.8 to 52.2 mg/l in the treated water discharged into the river course. The minimum value of COD in the influent water measured in 1989 was 117 mg/l, and the maximum concentration of 1232.5 mg/l was obtained in 1990. Figure (32) shows the COD values ranged from 83 to 361mg/l in Site III, 22 to 82 mg/l in Site IV, 20 to 182mg/l in Site V and 24 mg/l to 749 mg/l in Site VI.

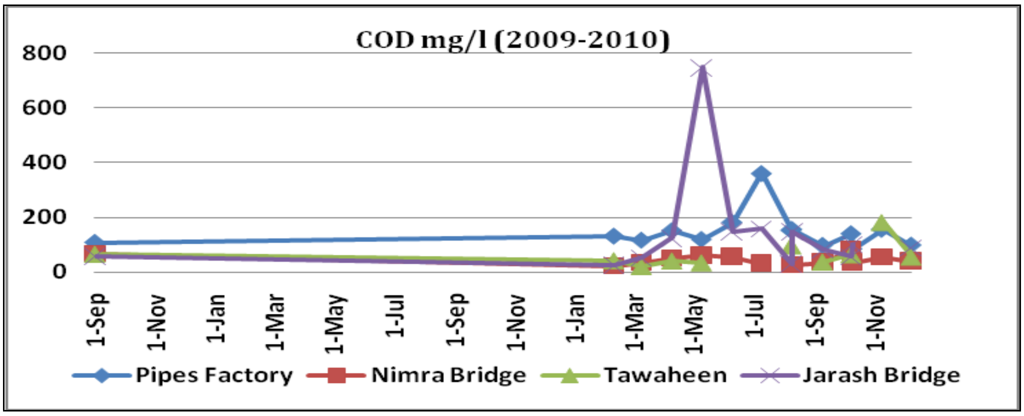


Figure 32: Variations of COD values in the different testing sites.

Before 2008, the maximum COD was 676 mg/l in all location was Site VI in 1989 which is higher than the highest value measured recently in the same site by around 75 mg/l, while the minimum value obtained in same year was 10.04 mg/l in Site IV. Figure (33) for COD in King Talal Dam water shows a minimum value of 19.49 mg/l in March 2010, while a maximum value of 48 mg/l was measured in June 2010. The mean value for COD in KTD was 33.8 mg/l during the observation period. As a result of this analysis, a decreasing in COD values has been measured throughout the Zarqa River and in KTD. This was a major direct result of the improved treatment in Samra wastewater treatment plant.

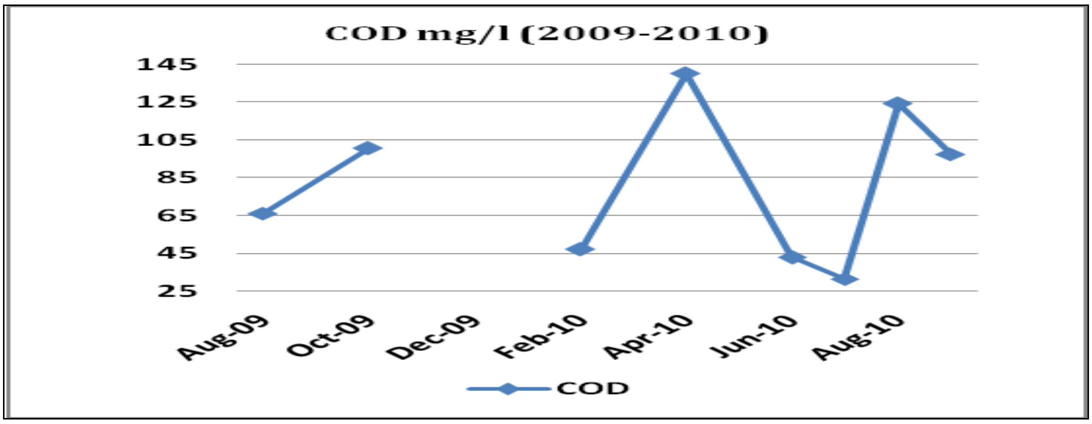


Figure 33: Fluctuation for COD values in KTD.

6.2.2 Biochemical Oxygen Demand (BOD_5 mg/l)

BOD is the most widely used parameter to define the strength of a municipal or organic industrial wastewater, and for evaluating the efficiency and performance of WWTP. The effluents of the new wastewater treatment plant have BOD_5 values ranged from 6.4 to 12.9 mg/l. These values are within the limits of the Jordanian standard for treated wastewater to be discharge into stream and water bodies. The minimum value of BOD_5 in the effluents to the old WWTP was 60 mg/l in 1989, and the maximum 240 was obtained in 2005. Figure (34) shows the fluctuation of BOD values along the river course.

The BOD concentrations along the river from the outlet of KS to the King Talal Dam are within the allowable Jordanian standard. The new KS effluent contain low concentration of BOD because of its high efficiency, with positive impacts on the water quality of Zarqa River, King Talal Dam and lands irrigated with their water. The data given in Table 32 show that the minimum value of BOD_5 for site 1 was 5 mg/l measured in summer, and 6.2 mg/l in site II.

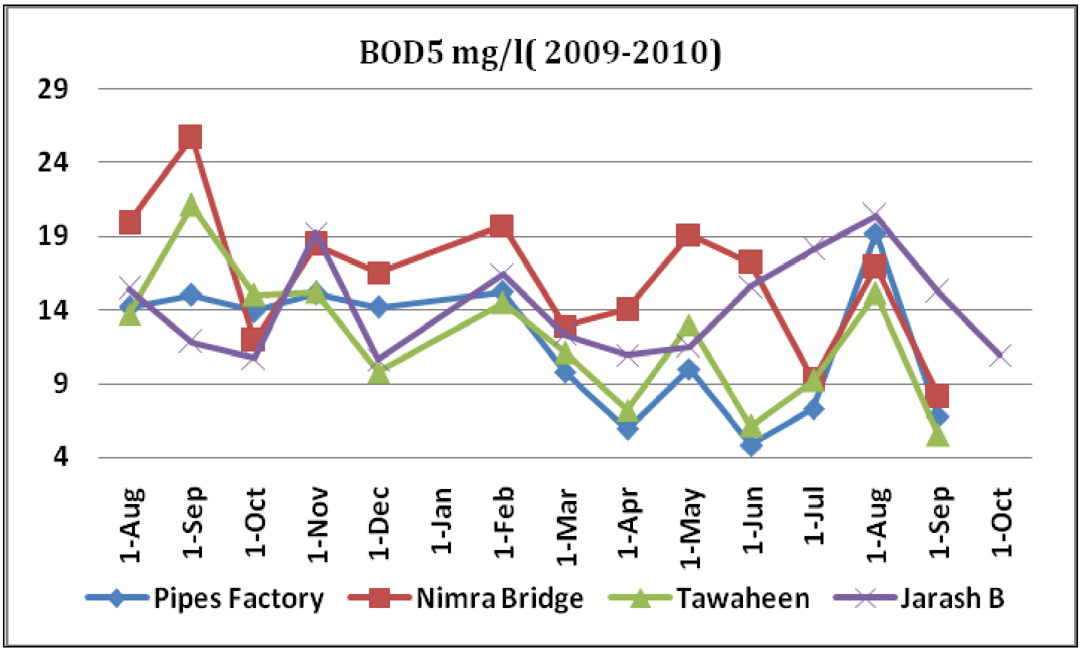


Figure 34: Fluctuations of BOD_5 along the river course.

The maximum BOD value was 25.7 mg/l in Nimra Bridge sampling site, while the minimum BOD value was 4.8 mg/l in the Site III. Along the river, as a result of self purification processes, the BOD decreases from Site IV to Site V, however, the presence of algae and the natural re-aeration resulted in enhancing the oxidation process.

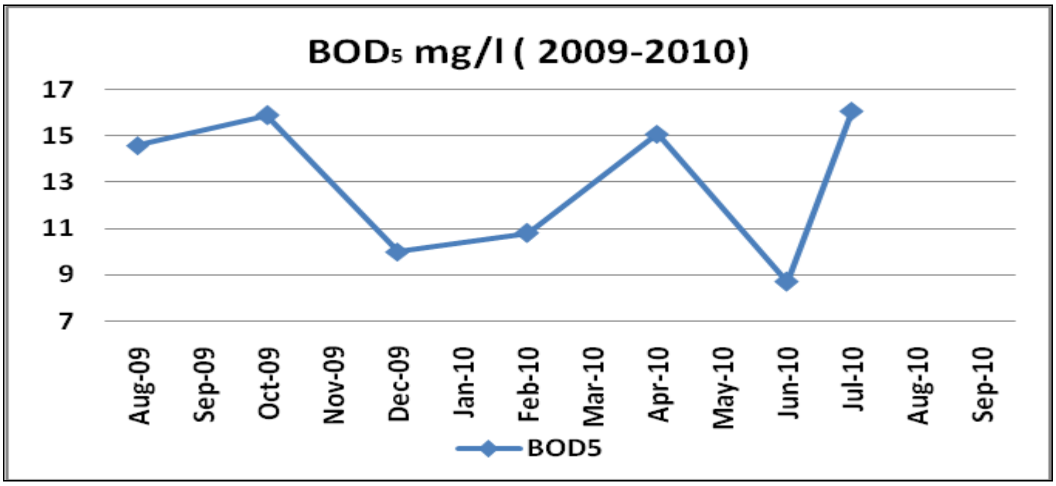


Figure 35: Fluctuations of BOD_5 concentration in KTD.

6.3 Correlation analyses

It is called a bivariente method, the correlation analysis is used to examine each pair of measurement variables to determine whether the two measured variables tend to move together, whether large values of one variable tend to be associated with large values of the other (positive correlation), whether small values of one variable tend to be associated with large values of the other (negative correlation), or whether values of both variables tend to be unrelated (correlation near 0, zero).

6.3.1 Pipe Factory correlation analysis:

A correlation matrix Table (25) shows a strong correlation of EC with most of the variables such as Na, Ca, K, SO_4, HCO_3 and Cl. The relationships between HCO_3 with Na, Ca and Cl, Na with Cl are very strong with values of more than 0.80. These indicate that e.g. Na and Cl have the same source or dissolution of halides (NaCl and KCl); in this Site the ratio of Na/ Cl is 0.99, figure (36).

Figures (37, 38 and 39) show the Bivariant diagrams for Na-HCO_3, HCO_3- Cl and Cl-HCO_3 relations.

Table 25: Correlation coefficients matrix between the different anions and cations in Site III water samples (n=12).

Para-meter	EC	BOD 5	Na	Ca	K	Mg	HCO3	SO4	NO3	Cl	PO4	COD	TDS
pH													
EC	1.00												
BOD_5	0.30	1.00											
Na	0.95	0.25	1.00										
Ca	0.80	0.42	0.70	1.00									
K	0.88	0.62	0.83	0.13	1.00								
Mg	0.63	0.15	0.48	0.29	-0.24	1.00							
HCO_3	0.95	0.41	0.84	0.83	0.11	0.69	1.00						
SO_4	0.69	-0.06	-0.14	0.20	-0.40	0.07	-0.07	1.00					
NO_3	0.19	0.61	0.25	0.20	0.09	-0.09	0.19	-0.16	1.00				
Cl	0.94	0.14	0.99	0.68	0.16	0.50	0.82	-0.13	0.15	1.00			
PO_4	0.32	0.02	0.36	0.18	0.19	0.25	0.32	-0.21	0.33	0.34	1.00		
COD	0.09	0.64	0.02	0.09	-0.08	0.08	-0.05	0.59	-0.13	0.06	-0.29	1.00	
TDS	1.00	0.30	0.95	0.80	0.11	0.63	0.95	0.00	0.19	0.94	0.32	0.09	1

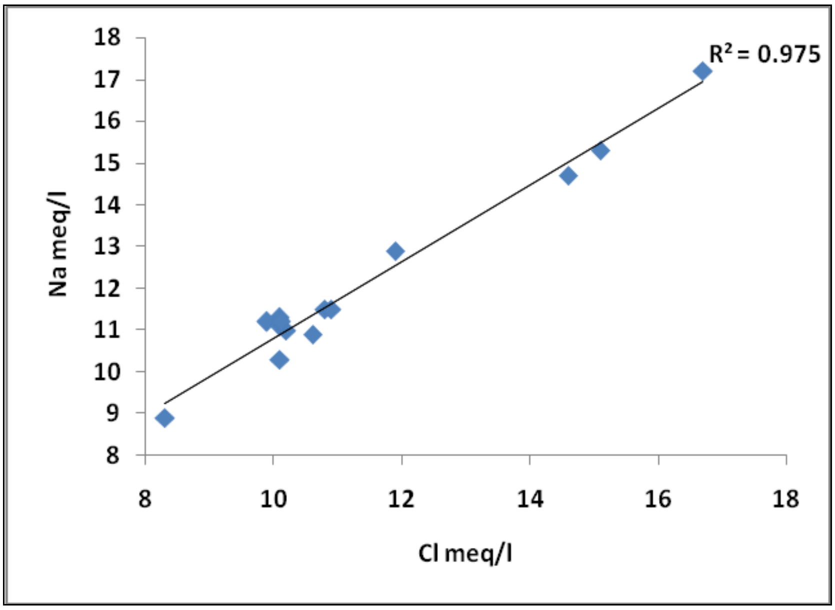


Figure 36: Bivariant diagram for Na and Cl.

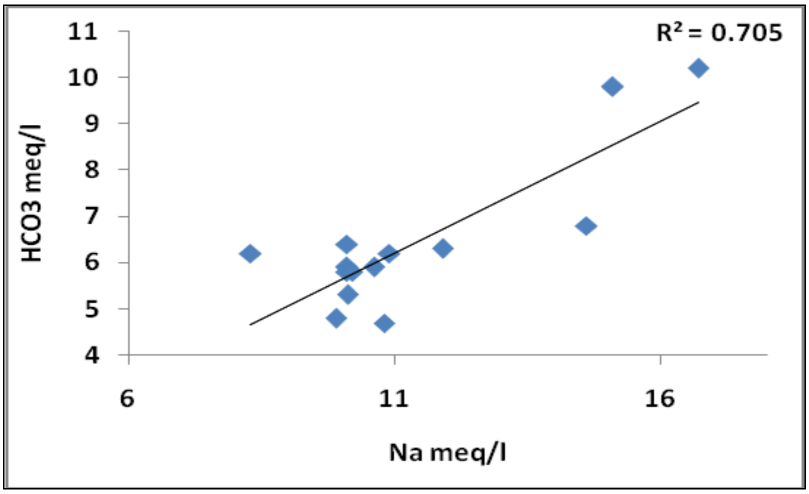


Figure 37: Bivariant diagram for Na and HCO3.

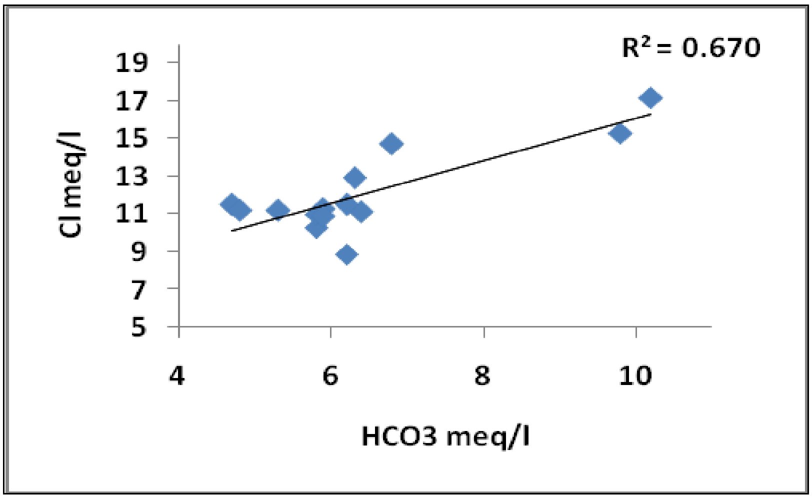


Figure 38: Bivariant diagram for HCO3 and Cl.

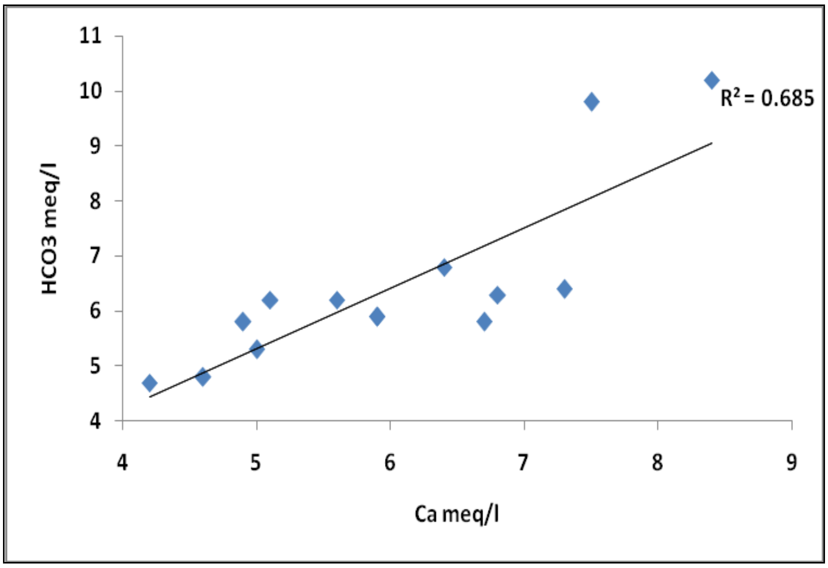


Figure 39: Bivariant diagram for Cl and HCO3.

6.3.2 Nimra Bridge correlation analysis:

Table (26) shows the correlation matrix for chemical constituents measured in the site, it's noticed that EC has a high relation with Na, Ca, K, HCO_3 and Cl. In addition to correlation between Na- HCO_3, Ca-HCO_3, HCO_3-Cl and Na-Cl.

Figures (40 and 41) show Bivariant diagrams for Na- Cl and Ca -HCO3, which indicate the same source or dissolution of carbonates and halite.

Table 26: Correlation coefficients matrix for the sampling Site IV (n=12).

Parameter	EC	BOD 5	Na	Ca	K	Mg	HCO 3	SO4	NO3	Cl	PO4	COD	TDS
pH													
EC	1.00												
BOD5	0.30	1.00											
Na	0.95	0.25	1.00										
Ca	0.80	0.42	0.70	1.00									
K	0.75	-0.26	0.89	0.13	1.00								
Mg	0.63	0.15	0.48	0.29	-0.24	1.00							
HCO3	0.95	0.41	0.84	0.83	0.11	0.69	1.00						
SO4	0.64	-0.06	-0.14	0.20	-0.40	0.07	-0.07	1.00					
NO3	0.19	0.61	0.25	0.20	0.09	-0.09	0.19	-0.16	1.00				
Cl	0.94	0.14	0.99	0.68	0.61	0.50	0.82	-0.13	0.15	1.00			
PO4	0.32	0.02	0.36	0.18	0.19	0.25	0.32	-0.21	0.33	0.34	1.00		
COD	0.09	0.69	0.02	0.09	-0.08	0.08	-0.05	0.59	-0.13	0.06	-0.29	1.00	
TDS	1.00	0.30	0.95	0.80	0.11	0.63	0.95	0.00	0.19	0.94	0.32	0.09	1

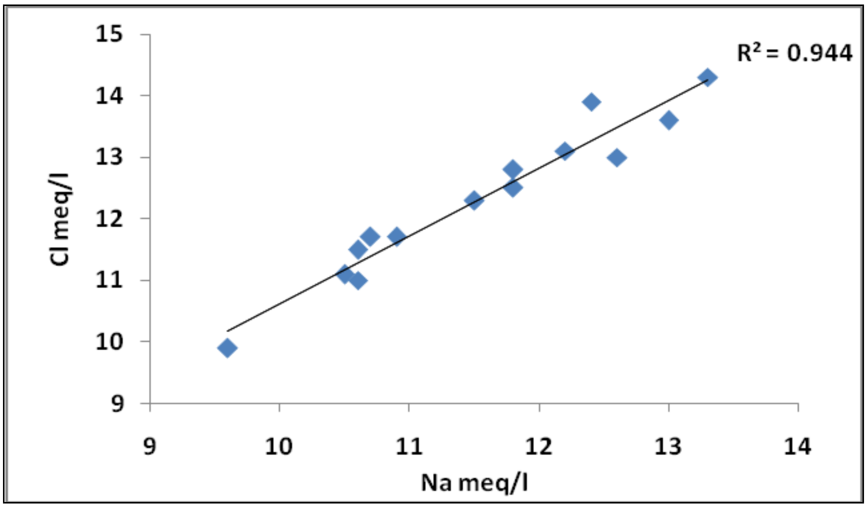


Figure 40: Bivariant diagram for Na and Cl.

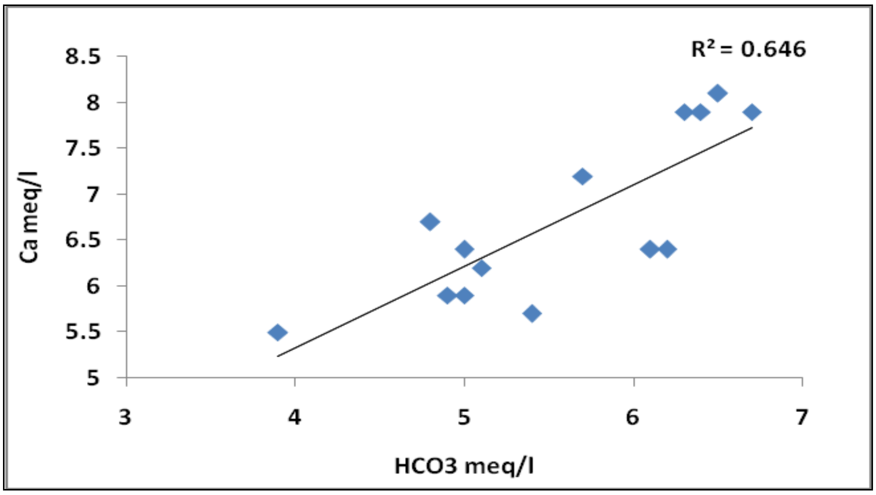


Figure 41 : Bivariant diagram for Ca and HCO3.

6.3.3 Tawaheen El Edwan correlation analysis:

Table (27) shows the correlation matrix for chemical constituents measured, that EC are strongly correlated with Ca, K, HCO_3, Cl and PO_4, in addition to Ca- HCO_3, Na-Cl and Ca-PO_4 relations.

Figures (42 and 43) show Bivariant diagram for Na-Cl and HCO_3-Ca relations.

Table 27: Correlation coefficients matrix for the sampling Site V (n=12).

Parameters	EC	BOD5	Na	Ca	K	Mg	HCO3	SO4	NO3	Cl	PO4	COD	TDS
pH													
EC	1.00												
BOD5	0.17	1.00											
Na	0.64	-0.18	1.00										
Ca	0.80	0.47	0.33	1.00									
K	0.75	0.12	0.64	0.62	1.00								
Mg	0.40	-0.07	-0.08	0.00	0.26	1.00							
HCO3	0.91	0.16	0.39	0.80	0.65	0.49	1.00						
SO4	0.29	0.38	-0.05	0.29	0.27	0.26	0.11	1.00					
NO3	0.28	0.48	-0.12	0.55	0.40	-0.11	0.36	0.21	1.00				
Cl	0.76	-0.05	0.91	0.47	0.59	0.08	0.52	0.01	-0.09	1.00			
PO4	0.73	0.58	0.30	0.75	0.66	0.23	0.62	0.45	0.50	0.51	1.00		
COD	0.05	0.38	-0.51	0.43	-0.13	0.06	0.37	-0.27	0.66	-0.41	0.25	1.00	
TDS	1.00	0.17	0.64	0.80	0.75	0.40	0.91	0.29	0.28	0.76	0.73	0.05	1.00

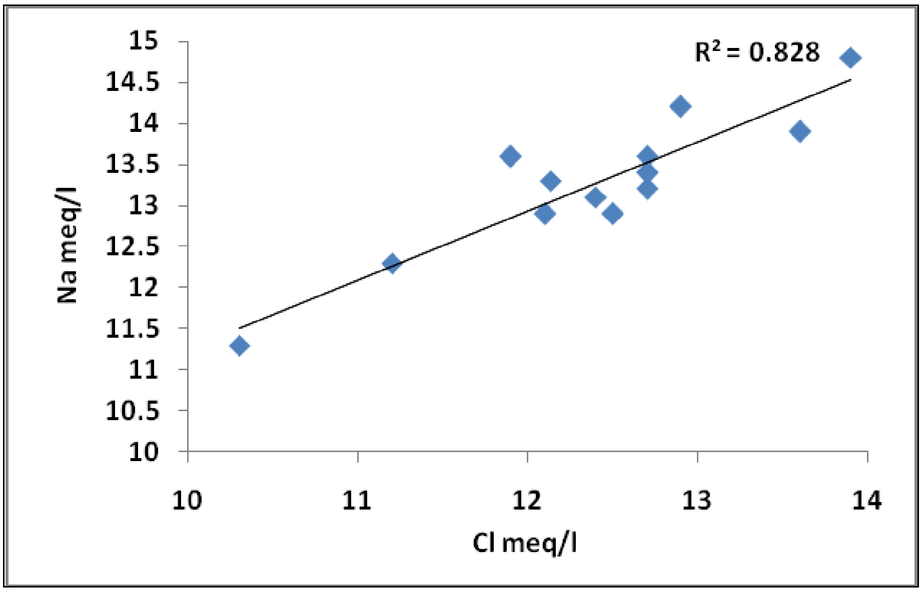


Figure 42: Bivariant diagram for Na and Cl.

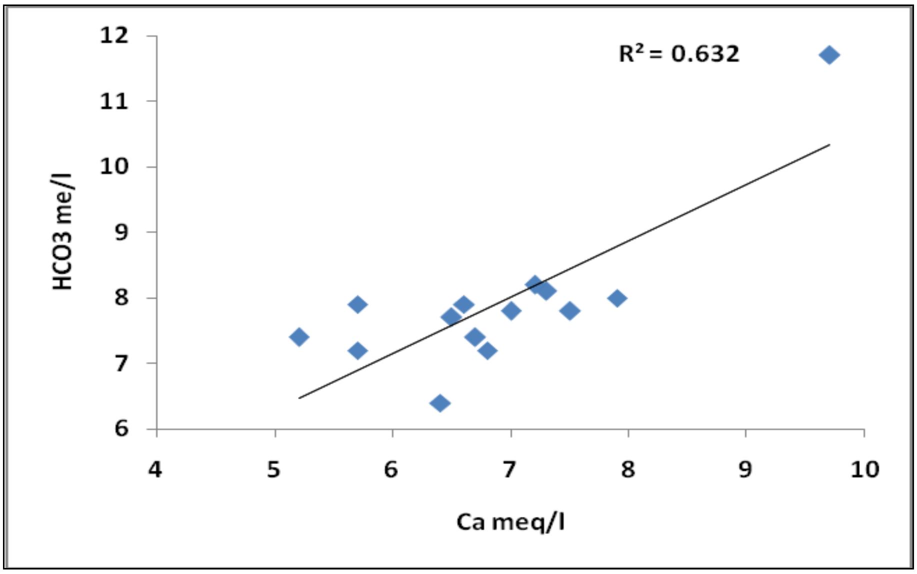


Figure 43: Bivariant diagram for HCO3 and Ca.

6.3.4 Jarash Bridge correlation analysis:

The correlation matrix for chemical constituents measured in table (28), which shows the EC is correlated with variables such as Na, K, HCO3 and Cl, in addition to Ca-HCO3 and Na-Cl. Figures (44) shows bivariant diagram for Na-Cl relation.

Table 28: Correlation coefficients matrix for the sampling site VI (n=12).

Parameters	EC	BOD5	Na	Ca	K	Mg	HCO3	SO4	NO3	Cl	PO4	COD	TDS
pH													
EC	1.00												
BOD5	-0.04	1.00											
Na	0.75	0.12	1.00										
Ca	0.49	0.17	0.68	1.00									
K	0.72	-0.20	0.76	-0.01	1.00								
Mg	0.51	-0.40	0.43	-0.30	0.16	1.00							
HCO3	0.76	-0.05	0.26	0.71	0.20	0.71	1.00						
SO4	0.34	-0.09	0.41	-0.11	0.23	0.29	-0.21	1.00					
NO3	0.12	-0.07	-0.03	0.61	-0.05	-0.52	0.13	0.02	1.00				
Cl	0.81	0.05	0.96	0.09	0.03	0.48	0.30	0.46	-0.04	1.00			
PO4 l	0.04	0.18	0.28	0.00	-0.40	-0.10	-0.09	-0.19	0.22	0.25	1.00		
COD	0.17	0.70	-0.15	-0.02	0.29	0.17	0.30	0.02	0.66	-0.19	-0.36	1.00	
TDS	1.00	-0.04	0.75	0.49	0,83	0.51	0.76	0.34	0.12	0.81	0.04	0.17	1.00

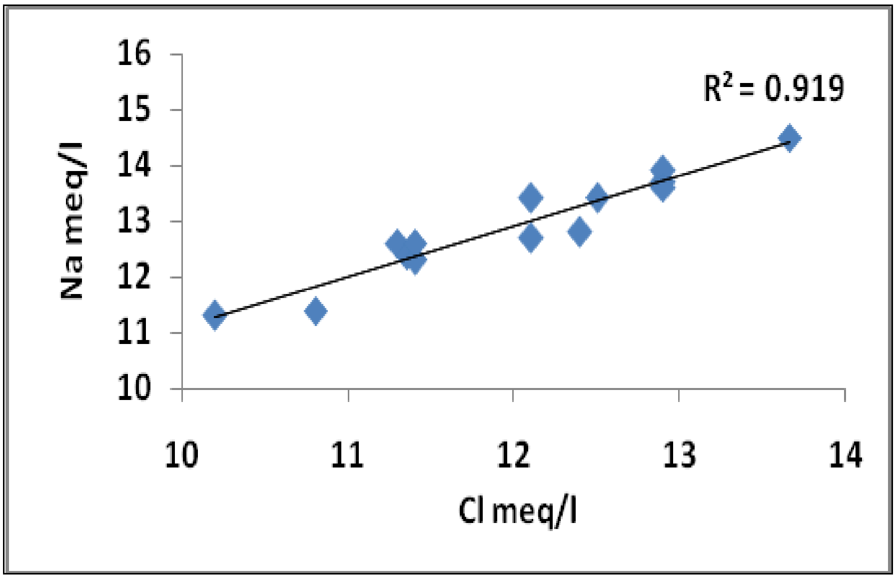


Figure 44: Bivariant diagram for Na and Cl.

6.3.5 King Talal Dam correlation analysis:

In King Talal Dam there was a high relationship between variables shown in the correlation matrix for chemical constituents measured in table (29), which shows the EC are strongly correlated with most variables, in addition to Ca- Mg, Na-Mg and Na-HCO3, Ca-HCO3, Mg-HCO3, Mg-NO3, Mg-Cl and SO4-PO4.

Figures (45, 46 and 47) show the Bivariant diagram for HCO3 and Mg, Ca and Mg and for HCO3 and Na.

Table 29: Correlation coefficients matrix for the sampling site VII (n=9).

Parameter	EC	BOD5	Na	Ca	K	Mg	HCO3	SO4	NO3	Cl	PO4	COD	TDS
EC	1.00												
pH	0.47												
BOD5	0.70	1.00											
Na	0.89	0.75	1.00										
Ca	0.87	0.51	0.58	1.00									
K	0.46	-0.33	0.87	0.52	1.00								
Mg	0.95	0.50	0.75	0.87	0.56	1.00							
HCO3	0.98	0.65	0.83	0.89	0.54	0.92	1.00						
SO4	0.18	0.24	-0.16	0.50	0.34	0.39	0.14	1.00					
NO3	0.73	-0.10	0.47	0.81	0.53	0.73	0.79	0.18	1.00				
Cl	0.86	0.71	1.00	0.52	0.14	0.73	0.80	0.21	0.43	1.00			
PO4	-0.10	-0.10	-0.49	0.33	0.40	0.09	-0.04	0.71	0.09	0.54	1.00		
COD	0.38	0.43	0.21	0.34	0.40	0.41	0.39	0.36	0.02	0.20	0.10	1.00	
TDS	1.00	0.70	0.89	0.87	0.69	0.95	0.98	0.18	0.73	0.86	-0.10	0.38	1.00

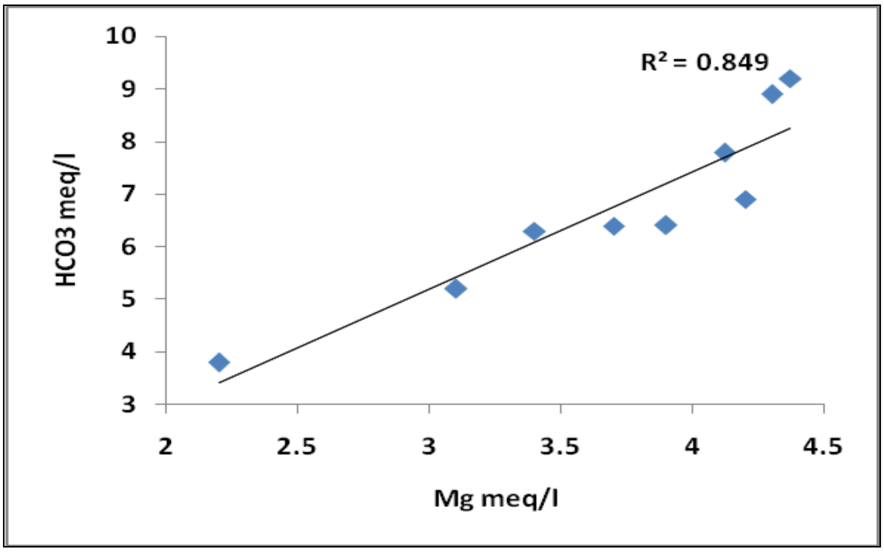


Figure 45: Bivariant diagram for HCO3 and Mg.

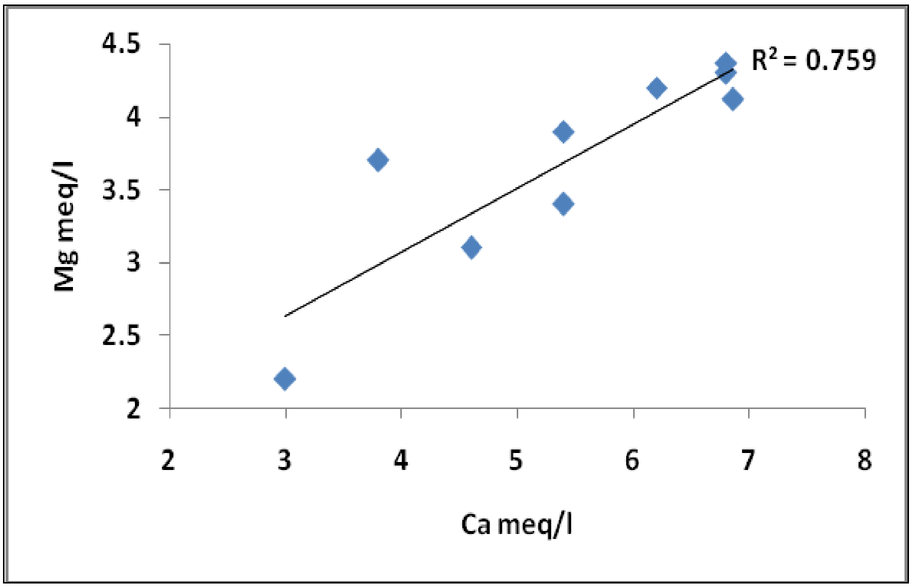


Figure 46: Bivariant diagram for Ca and Mg.

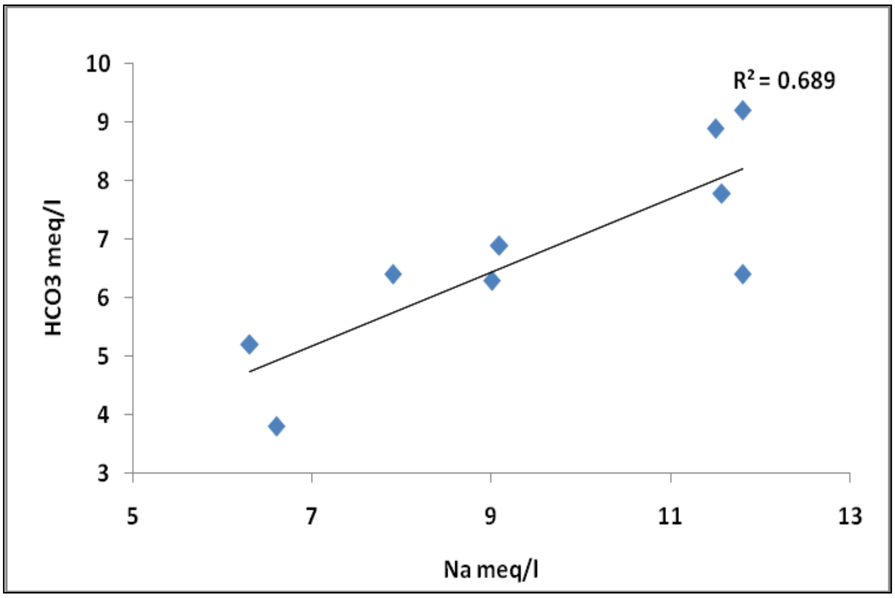


Figure 47: Bivariant diagram for HCO3 and Na.

7 Irrigation and water quality changes during infiltration

7.1 Recycled water

Jordan needs to conserve its water resource by recycling of treated wastewater for use in irrigation. Treated wastewater mixed with fresh water in King Abdullah Canal (KAC) and used in agriculture in the Central Jordan Valley.

The water quality changes is taking place during infiltration, and their effects on soil characteristic, crop yield and groundwater depend on, the chemistry of applied water. Infiltration water samples collected via suction cups installed at different depths of 20, 40, 60 and 80cm were collected for analyses to study the changes taking place during infiltration.

7.2 The King Abdullah Canal (KAC)

KAC conveys fresh water that constitutes a blend of surface water mixed with ground water from the north to the central valley for a distance of 65 km. A mixture of treated wastewater and fresh canal water is used to irrigate the southern parts of the Jordan valley. The chemical composition of KAC water is given in Table (30).

Figure 48: King Abdullah Canal.

Table 30: Chemical analysis of King Abdullah Canal mixing water.

Date	Sep-09	Nov-09	Mar-10	Jun-10	Aug-10	Sep-10
EC μs/c	1093	888	890	1982	1105	1237
pH	8.06	8.03	8.25	7.92	8.03	8.31
BOD5 mg/l	10	5		10	5	5
Na meq/l	3.57	3.78	0.14	8.4	5.296	8.3
Ca meq/l	3	1.39	3.17	4.4	2.2	2.8
K meq/l	0.78	0.13	0.14	0.86	0.424	0.87
Mg meq/l	2.1	0.97	2.87	4.8	2.2	0.6
HCO3 meq/l	4.08	4.61	4.59	6.8	6.4	3.6
SO4 meq/l	1.17	1.82	0.89	1.201	0.694	0.463
NO3 meq/l	0.17	0.18	0.14	0.92	0.69	0.09
Cl meq/l	2.94	2.72	2.94	6.9	6.4	8.2
PO4 meq/l	0.117	0.123	0.118	1.113	0.0168	0.0212
COD mg/l	20.38	41	19.49	48	36	38
TDS mg/l	699.52	568.32	569.6	1268.48	707.2	791.68

The KAC water is a major source of irrigation water in the Jordan Valley.

7.3 Study Area (Deir Alla) test site

Deir Alla is located in the Northern Ghor along the main Jordan Valley road, to the north of the Dead Sea. The average temperature in Deir Alla ranges from 15°C in January to 43°C in August. King Abdullah Canal (KAC) passes through Deir Alla city forming the major irrigation water source. Suction cup tests were conducted on several farms in this area.

7.3.1Soil profiles

A soil profile is a vertical section cut into the soil. In the Jordan Valley, the soil depth is about one meter, but it is often shallower than that. The soil profiles were evaluated by digging a pit in the soil and examine the face of the soil. The profiles show

horizontal layering; horizons, which are divided in a very general sense, into A, B and C horizons, Table (31).

The A horizon, the surface layer. is generally darker in colour and higher in organic matter than the other horizons. The B horizon is lighter in colour, lower in organic matter, higher in clay content and more dense (compacted) than A horizon. The C horizon is the parent material from which the A and B horizon were developed.

Soil horizons develop over time. Many soils in the Jordan valley are young and not highly developed.

Table 31: Soil profile with A, B and C horizons, Site III in the study area.

Horizon depth	Horizon symbol	Texture
20 cm	A	Loamy sand
50 cm	B	Loamy-clayey sand
80 cm	C	Sand

Figure 49: Soil profile in farm at UTM Coordinates (WGS 1984): Longitude 32°09'5.15‘N, Latitude 35°36'.702‘E.

Soil A is loamy sand in the upper 45 cm with a rapid transition to clean gravel and cobbles below, and is considered of higher field capacity. Soil B is a profile with

loamy clayey sand uniformly distributed. The carbonate concentration and colour does not show a (B) regolith horizon but this is due to the farming activity and the high saline irrigation water used there.

In the soil A water will accumulate above the textural interface and has good permeability, low salinity, and no clay (marl) content. This type of soil is suitable for all types of crops. B soil is shallower than A horizon, less permeable tend to pull water downward, and slightly more saline. C horizon is shallow and has high salinity and low permeability.

A and B soils in Deir Alla constitute the total area, which makes the soil more suitable for growing vegetables and field crops.

7.4 Suction cups (SC)

The tests were carried out in order to study the effect of different water quality during infiltration processes on the groundwater resources and soils. The suction cups were installed in different sites in Jordan Valley (Deir Alla) farms. The water quality changes taking place during infiltration were compared for different types of applied water, starting by rain water fresh water and different types of treated wastewaters. These tests were performed in Queen Alia Airport (WERSC, 1989), Hussein Gardens and Wadi Es Sir Wastewater effluents (Jasem, 2009).

7.4.1 Jasem studied the infiltration water at different sites using suction cups with the following results:

a. King Hussein Gardens rainfed area

Suction cups were installed at different depth of 20, 40 and 60 cm into the soil in King Hussein Gardens in Amman to study the effects of soils and water rock interactions on the infiltrated rain water chemistry.

When comparing the composition of the applied water and that of the infiltrated water at depths of 20, 40 and 60 cm, it can be noticed that the EC increased from 60µS/cm at the surface to about 688µS/cm at 60 cm depth, Table (32). Where this increase can be attributed to water evaporation and dissolution of soil minerals.

Figure 50: Suction cups in King Hussein Gardens test site (Jasem, 2009).

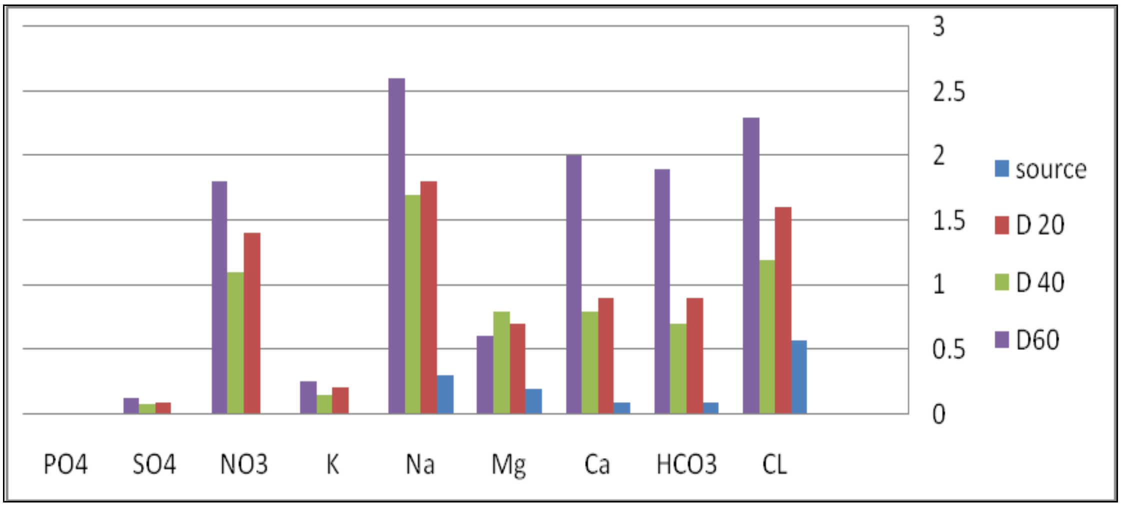


Figure 51: Bar diagram showing the chemical composition of rain water and changes taking place during infiltration to different depths in King Hussein Gardens test site.

Figure (51) shows the increase in the concentrations of chemical parameters is compatible with depth. The effects during infiltration are: increases in the concentration of the different parameters as a direct result of dissolution of soil minerals and high evaporation from the top soil.

Table 32: Results of analyses of the applied water (Rain water) and the changes taking place during infiltration in King Hussein gardens test site (Jasem, 2009).

Parameters	Applied water	Depth 20 cm	Depth 40 cm	Depth 60 cm
EC (µS/cm)	59	604	520	688
Cl (meq/l)	0.58	1.6	1.2	2.3
HCO_3(meq/l)	0.1	0.9	0.7	1.9
Ca (meq/l)	0.1	.0.9	0.8	2
Mg (meq/l)	0.2	0.7	0.8	0.6
Na (meq/l)	0.3	1.8	1.7	2.6
K (meq/l)	.008	0.2	.15	0.25
NO3 (meq/l)	.004	1.4	1.1	1.8
SO4 (meq/l)	0	0.08	0.08	0.2
PO4 (meq/l)	.001	.002	N.A	.003

N.A: Not analyzed.

b. Wadi Es sir green house using freshwater:

When comparing the chemistry of the applied water and that of infiltrated water at depths of 20, 40 and 60 cm, it was found that the EC increased from 567µS/cm at the surface to about 1560µS/cm at 60cm depth, and a gradual increase at 20 and 40 cm depth. This is compatible with the increase in Cl, Ca, Mg, NO_3 and Na ions concentrations. The temporary increase in EC and other parameters at a depth of 20 cm can be attributed to evaporation and slight dissolution of soil minerals.

Element concentrations gradually increase with depth which show evaporation, dissolution of soil minerals and that fertilizers used in this green house are percolating down. There is an increase in the Phosphate concentrations of the applied water to a depth of 40 cm. Worth mentioning here is that the green house (plant nursery) is irrigated daily which does not allow the topsoil to dry and hence not allowing capillary rise of salt- laden deeper water to the surface to evaporate.

Table 33: Chemical analysis of the applied water and its changes with depth in the green house test site (after Jasem, 2009).

Parameters	Source	Depth 20 cm	Depth 40 cm	Depth 60 cm
EC (µS/cm)	567	687	818	1569
Cl (meq/l)	2	4.6	6	7.4
HCO3 (meq/l)	3.2	2	1.6	2.2
Ca (meq/l)	2.1	2.5	2.7	3.8
Mg (meq/l)	1.8	1.1	1.6	1.8
Na (meq/l)	1.7	4.3	5.2	7.3
K (meq/l)	0.08	0.4	0.61	0.54
NO_3 (mg/l)	0.95	1.5	1.5	2.7
SO_4 (meq/l)	0.17	0.04	0.05	0.06
PO_4 (meq/l)	0.0009	0.002	0.001	0.0013

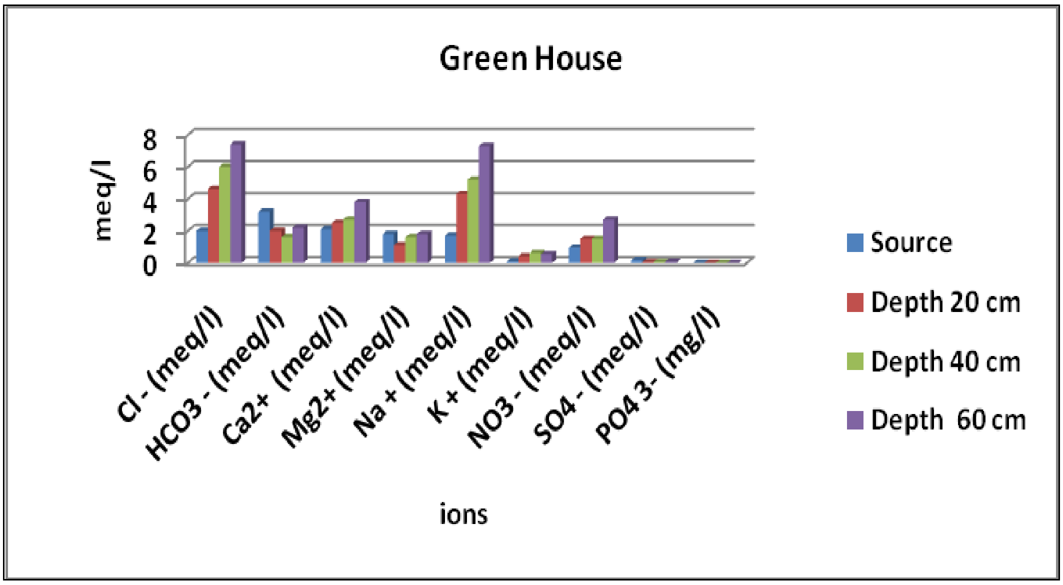


Figure 52: Bar diagram showing the chemical analysis of the applied water and its changes with depth in the green house test site (Jasem, 2009).

c. Wadi Sir Wastewater treatment plant (Jasem, 2009):

When comparing the chemistry of the applied water and that of the infiltrated water at depths of 20, 40 and 60 cm, it was found that the EC increased from 1365 µS/cm at the surface to about 3170 µS/cm at 20 cm depth, then it decreased to reach 2883 µS/cm at 40 cm depth and reach 2236 µS/cm at 60cm depth (Jasem, 2009).

This increase is compatible with the increase of Cl, HCO_3, Ca, K and NO_3 concentrations at a depth of 20cm. This increase is explained by evaporation from the soil, because the evaporated water left the ions in the soil. Suction cups collected the water from the soil in a time period extending an average of around 72 hours after irrigation. Therefore, and due to evaporation from the soil surface the concentrations of different ions increase in the upper parts the soil. The water salinity is therefore highest in the topsoil and it decreases gradually with depth.

At a depth of 60 cm the salinity of soil water expressed in EC terms of 2236 µS/cm is higher than the irrigation water of 1365 µS/cm, because upon renewed application of irrigation water that water will mix with the higher EC water in the topsoil and will percolate down as a mixture of the two waters. This gives a higher EC infiltrating to soil depths of more than 60 cm compared to that of irrigation water.

Of course the salinities of the soil waters at all depths depend on the irrigation frequency, amount of applied irrigation water and weather conditions (evaporation factors).

Mg ions increased at a depth of 60cm to reach 19 meq/l while in irrigation water it has a concentration of 2 meq/l. Na ions reach the highest value at the depth of 40, then a decrease occurred most probably as a result of ion exchange.

The soil in Wadi Sir Wastewater treatment plant has high salinity which adds to the increase in salinity during down percolation.

Table 34: Chemical analyses of the applied water and changes with depth in the chemical composition during infiltration in Wadi Sir WWTP.

Parameters	Source	Depth 20cm	Depth 40 cm	Depth 60 cm
EC (µS/cm)	1365	3170	2883	2235.5
Cl (meq/l)	8	27	15.7	20.15
HCO_3 (meq/l)	4.3	12.1	7.5	11
Ca (meq/l)	3.7	7.5	4.6	4.3
Mg (meq/l)	2	14.5	12.1	18.9
Na (meq/l)	7.12	20.4	9.7	9.1
K (meq/l)	0.83	1.8	0.2	1
NO_3 (meq/l)	2.1	3.83	2.11	2.55
SO_4 (meq/l)	1.52	N.A	N.A	N.A
PO_4 (meq/l)	0.01	N.A	N.A	N.A

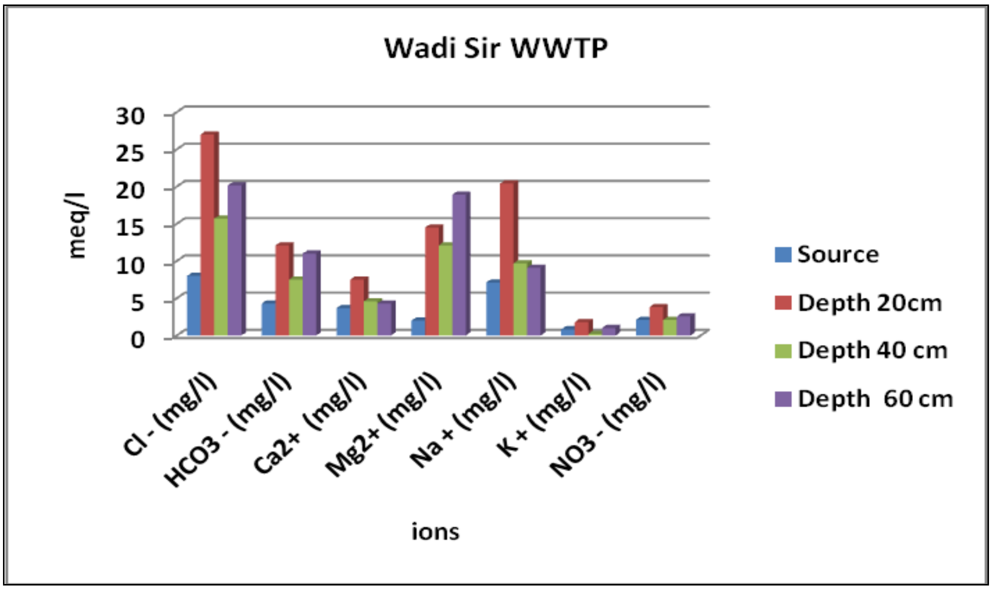


Figure 53: Bar diagram showing the chemical analysis of the applied water and its changes with depth in Wadi Sir WWTP (Jasem, 2009).

d. Fuheis wastewater treatment plant (Jasem, 2009):

When comparing the chemistry of the applied water and that of the infiltrated waters at depths of 20, 40 and 60 cm, it can be observed that the EC increased from 1629 µS/cm at the surface to about 2006 µS/cm at 60 cm depth, gradually increasing at 20 and 40 cm depths.

Contrary to Wadi Sir Wastewater treatment plant the salinity here increases with depth. The main factors leading to that are the type of soil (Silty sand soil with a very low capillary fringe depth of a few centimeters) and the salinity residues in the soil because thin soil has not been irrigated before. The increase in salinity is a mere result of salt dissolution from the soil profile and the downward movement with the down percolating water. Added to that are the salts accumulated in the most topsoil as a result of evaporation, which dissolution and downward movement will- with the infiltration water- contributes to the salinity of the water at depth.

The slight decrease with depth in the concentrations of Ca and Mg and the strong decrease in HCO_3 is an indication of precipitation of carbonates and ion exchange in the clays within the soil matrix. This increase is compatible with the increase in Cl and Na ions at depth of 60cm. Mg ions decrease at depth of 60cm to reach 1.2 meq/l while in the applied water the concentration was 4.6 meq/l this might be a result of dolomitization processes.

Na ions reach the highest value at the depth of 60. The soil around Fuheis waste water treatment plants formed from the weathering of sandstone containing some clay minerals.

Table 35: Chemical analysis of the applied water and its changes with depth in Fuheis WWTP test site.

Parameters	Source	Depth 20 cm	Depth 40 cm	Depth 60 cm
EC (µS/cm)	1629	1450	1803	2006
Cl (meq/l)	7.5	7.8	9.1	10.2
HCO_3 (meq/l)	6.8	1.9	1.6	2.4
Ca (meq/l)	2.4	2.3	1.8	2
Mg (meq/l)	4.6	2.1	1.7	1.2
Na (meq/l)	8.3	7.1	8.4	8.9
K (meq/l)	0.98	0.7	0.8	1
NO_3 (meq/l)	1.5	1.2	1.7	1.1
SO_4 (meq/l)	1.53	N.A	N.A	N.A
PO_4 (meq/l)	0.002	N.A	N.A	N.A

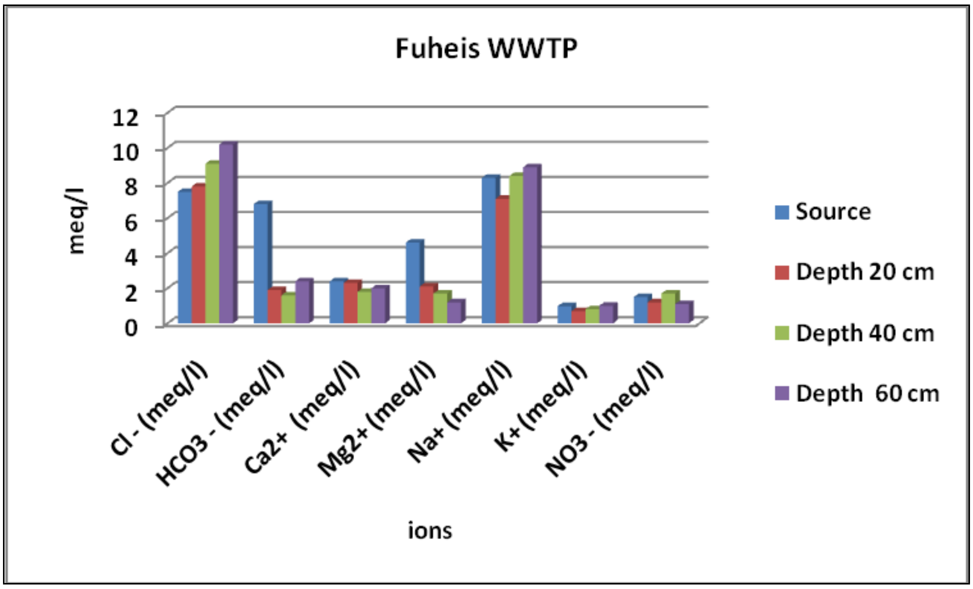


Figure 54: Bar diagram showing the chemical analysis of the applied water and its changes with depth in Fuheis WWTP test site (Jasem, 2009).

7.4.2 In the course of the present study the following sites were selected to install suction cups and test infiltration water:

a. Deir Alla test site I, II:

Two tests were done in this site, the first was not successful, and because of the nature of the soil profile that does not hold enough amounts of water. Then the suction cups were planted in another place having better conditions.

Water applied in this site was supplied from the King Abdullah Canal (KAC), this water is freshwater before mixing, the variation of chemical composition of the applied water and infiltrated water at depth 20, 40, 60 and 80 cm can be noticed on the EC values which increased from 1629 µS/cm at the source to 2006 µS/cm at 80 cm depth, Figure (55).

There were relative increases of sulfate and chloride concentrations relative to bicarbonates and carbonates. Whereas, the cations concentration ratio was stable during infiltration, most of the salinity parameters show a gradual increase with depth which indicates the dissolution of soil minerals and fertilizers.

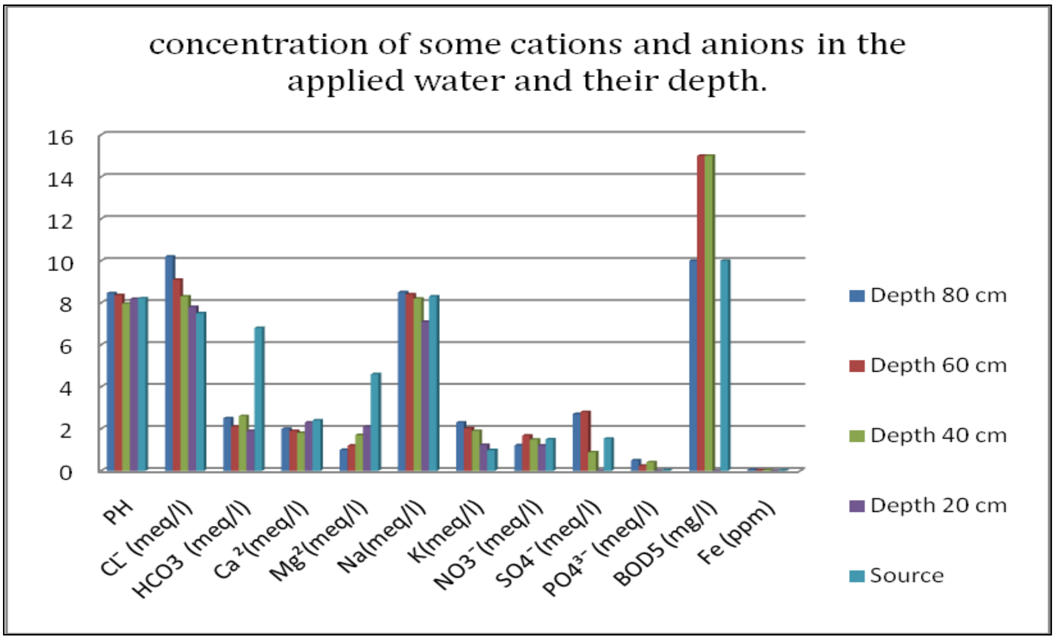


Figure 55: Bar diagram showing the development of the concentration of the different ions at Deir Alla test site II.

High rate of fertilizers are frequently used in farms, when these are not removed by plants or by leaching, they add to the salinity of the soil as indicated by the increase or stability of concentrations of PO_4 and NO_3 with depth. Also trace elements of Pb, Mn, Co and Zn were analyzed in the water samples but their concentrations were less than 0.01 ppm and show no important differentiations during infiltration.

Table 36: Composition of the applied water and the differentiations of infiltrated water in Deir Alla II test site.

Parameters	Source	Depth 20 cm	Depth 40 cm	Depth 60 cm	Depth 80 cm
EC µS/cm	1629	1598	1912	2106	2470
pH	8.21	8.19	7.96	8.36	8.46
Cl (meq/l)	7.5	7.8	8.3	9.1	10.2
HCO3 (meq/l)	6.8	1.9	2.6	2.1	2.5
Ca (meq/l)	2.4	2.3	1.8	1.9	2
Mg (meq/l)	4.6	2.1	1.7	1.2	1
Na (meq/l)	8.3	7.1	8.2	8.4	8.5
K (meq/l)	0.98	1.23	1.9	2.02	2.3
NO3 (meq/l)	1.5	1.2	1.49	1.68	1.21
SO4 (meq/l)	1.53	N.A	0.88	2.8	2.7
PO4 (meq/l)	0.031	N.A	0.41	0.24	0.5
BOD5 (mg/l)	10	N.A	14.8	15	10.3
Fe (ppm)	0.019	N.A	0.034	0.028	0.048

b. Deir Alla test III:

In this site a mixture of treated wastewater and fresh water were used also, but this water was with higher salinity than in the previous tests, Sites I and II.

The analytical results show that the EC values in the applied water and that of infiltrated water at depth of 20, 40 and 60cm (there is no sample at depth 80cm), increased from 1665 µS/cm at the surface to about 2170 µS/cm at 20cm depth, then it increased to reach 2683 µS/cm at 40cm depth and reach 2195 µS/cm at 60cm depth.

The increase is compatible with increasing Cl, HCO_3, Ca, K and NO_3 concentration at a depth of 20cm. This increase is explained by evaporation from the soil, because the evaporated water left behind the different ions in the soil. This is because suction cups collected the water from the soil in a time period extending at an average of around 72 hours after irrigation.

Therefore and due to evaporation from the soil surface, the concentrations of different ions increase in the top soil water. The water salinity is therefore highest in the topsoil and decreases gradually with depth.

At depth of 60cm the salinity of soil water expressed in EC terms of 2195µS/cm is higher than that of the irrigation water of 1665µS/cm, because upon renewed application of irrigation water, the water will mix with the higher EC water in the topsoil and will percolate down as a mixture of the two waters. This gives higher EC water infiltrating to soil depths of more than 60cm compared to that of irrigation water.

Of course the salinities of the soil waters at all depths depend on the irrigation frequency, amount of applied irrigation water and weather conditions (evaporation factors).

Na ions reach the highest value at the depth of 40, and then a decrease occurred most probably as a result of ion exchange or differential plant uptake.

Table 37: Composition of the applied water and the changes taking place during infiltration with depth in site III.

Parameters	Source	Depth 20cm	Depth 40cm	Depth 60 cm
EC(µS/cm)	1665	2170	2683	2195
Cl (meq/I)	9.3	13.9	14.2	16.4
HCO_3 (meq/I)	4.5	9.1	7.5	9.7
Ca (meq/I)	4	7.3	4.6	4.3
Mg (meq/I)	1.9	4.5	3.6	4.2
Na (meq/I)	7.1	11.2	13.7	12.5
K (meq/I)	.92	1.8	2.1	1
NO_3 (meq/I)	1.8	1.7	1.2	2.55
SO_4 (meq/I)	1.5	1.12	1.87	2.01
PO_4 (meq/I)	0.12	.36	.49	.34
BOD5 (mg/l)	9.7	20.1	15.2	N.A

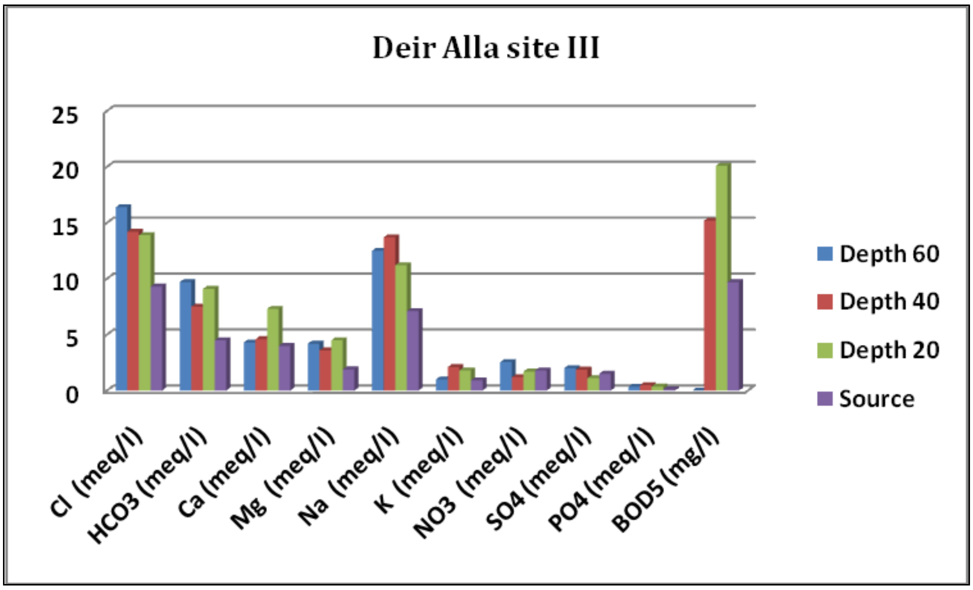


Figure 56: Bar diagram showing the chemical analysis of the applied water and its changes with depth in Deir Alla test site III.

The high salt concentration at the soil surface is due to high evaporation rates from wetted areas and the nature of soil water distribution associated with the drip irrigation system. Then, the salt concentration decreased until the second depth of 20cm, thereafter, salt concentration followed the bulb shape of the wetted soil volume under trickle irrigation. Irrigation water salinity is very important factor that should be managed with limited (deficit) irrigation. But increasing amount of applied saline water could result in a negative effect on crop yield and environment such as increasing average crop root zone salinity, nutrient leaching, water logging, increasing the drainage water load of salinity which might pollute ground water and other water sources.

c. Deir Alla test site IV:

The Vegetation type Orange Trees the main crops drip irrigation system used in this site. When comparing the applied water and the infiltrated water at depth of 20, 40, 60 cm and 80cm it can be noticed that the EC increased from 1856 µS/cm at the surface

to about 1941 μS/cm at 80 cm depth, this increase can be attributed to evaporation and dissolution of soil minerals.

The drip irrigation system provides an efficient method of irrigation in the Jordan valley. Most of the salinity parameters show small gradual increase in concentration with depth which indicates the dissolution of soil minerals and fertilizers.

High rate of fertilizers are frequently used in farms, if these are not removed by the crop or by leaching, they add to the salinity of the soil as indicated by the increasing concentration with depth.

The concentrations of K^{+}, Ca^{2+}, and Mg^{2+} are affected by cation exchange between the soil solution and soils.

Table 38: Composition of the applied water and the changes taking place during infiltration in forth farm test site.

Parameters	Source	Depth20cm	Depth40cm	Depth 60cm	Depth 80cm
EC(μS/cm)	1799	1856	1895	1920	1941
Cl (meq/I)	10.6	11.7	11.8	11.7	12.7
HCO_3 (meq/I)	4.9	4.4	4.1	4.1	4.8
Ca (meq/I)	5.7	5.8	6.6	6.12	6.8
Mg (meq/I)	3.9	3.4	3.7	3.6	3.6
Na (meq/I)	6.6	7.7	7.3	7.7	6.6
K (meq/I)	1.3	1.01	1.01	1.36	1.7
NO_3 (meq/I)	1.6	1.15	.1.46	1.4	.69
SO_4 (meq/I)	.96	1.3	1.5	1.5	.88
PO_4 (meq/I)	.044	.046	.087	.23	.017
BOD5 (mg/l)	14.9	18.6	15	N.A	N.A

The nitrate (NO_3^-) is characterized by its low interaction capability with most materials. The concentration decreased with depth, as a result of plant uptake. In addition, ammonium and nitrate concentrations are altered by biological processes (e.g.: nitrification).

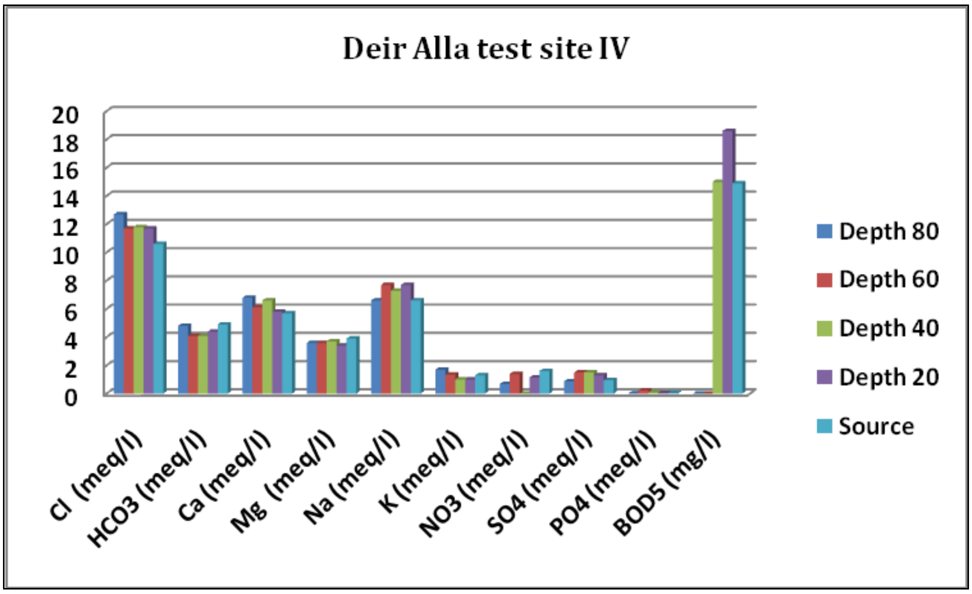


Figure 57: Bar diagram showing the chemical analysis of the applied water and its changes with depth in Deir Alla farm IV.

d. Deir Alla V

Institute of Agricultural Research, Training, Extension and Education:

This site belongs to the University of Jordan farm located in the central Jordan Valley; the station provides land, equipment and facilities for research on plants, soils, water and environment through field, laboratory work.

It is irrigated from KAC waters, suction cups set installed at depths of 20, 40, 60 and 80 cm, collected the water from the soil irrigated by a drip system.

The concentrations of different ions increase in the soil water due to evaporation from the soil surface. The water salinity is therefore highest in the topsoil and it decreases gradually with depth, as a result of frequent irrigation.

Table 39: Composition of the applied water and the changes taking place during infiltration in University farm test site.

Parameters	Source	Depth 20cm	Depth 40cm	Depth 60cm	Depth 80cm
EC(µS/cm)	1764	2240	2011	1854	1941
Cl (meq/I)	10.4	13.6	18.8	11.5	12.7
HCO_3 (meq/I)	4.8	5.8	7.6	4.8	4.8
Ca (meq/I)	5.6	6.6	8.4	5.64	6.8
Mg (meq/I)	3.8	4.4	3.4	2.24	3.6
Na (meq/I)	6.5	9.4	13.8	9.1	6.6
K (meq/I)	1.3	1.4	2.7	1.36	1.7
NO_3 (meq/I)	1.6	0.83	0.74	0.69	0.67
SO_4 (meq/I)	0.95	1.4	2.2	1.03	0.88
PO_4 (meq/I)	0.043	0.047	0.029	0.015	0.017
BOD5 (mg/l)	20.1	15.3	19.7	15.6	9.3

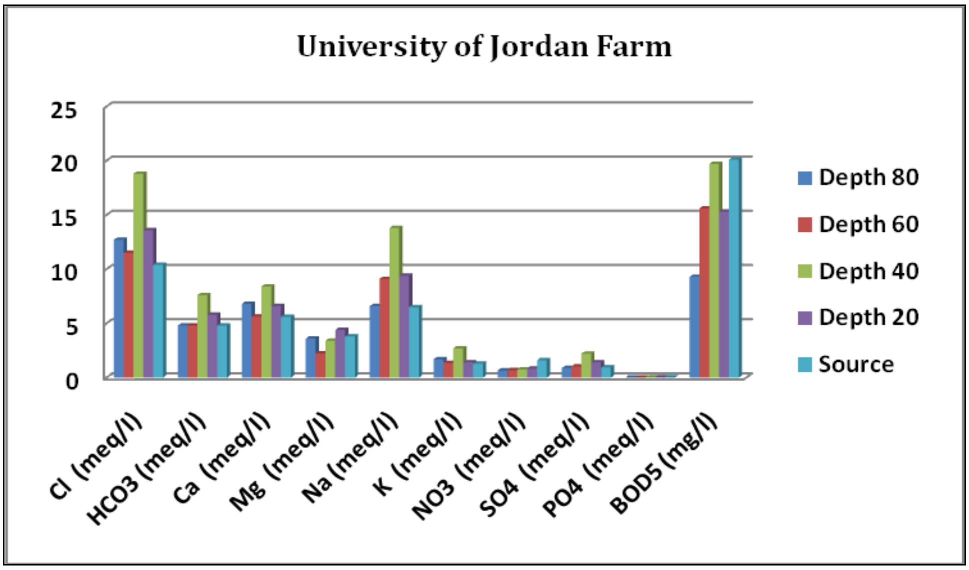


Figure 58: Bar diagram showing the chemical analysis of the applied water and its changes with depth in University of Jordan farm.

At the depth of 20 cm the salinity of soil water expressed in EC terms of 2240 µS/cm is higher than the irrigation water of 1764 µS/cm, because upon renewed application of irrigation water that water will mix with the higher EC water in the topsoil and will percolate down as a mixture of the two salinity waters.

The increase in the concentration of the different parameters is gradual and small as a result of excess irrigation using drip irrigation techniques.

In order to compare the changes in water composition during infiltration in different climatic zones using different water types in irrigation the following results are taken from studies performed at the Water Research and Study Centre - University of Jordan (WRSC,1989), and by (Jasem, 2009) in the course of her PhD study.

7.4.3 Treated water at Queen Alia International Airport (QAA) (WERSC, 1989)

Suction cups were installed at 25, 45cm depth, conducted by the Water Research and Study Centre in 1989, using the treated wastewater generated at the airport and other facilities.

It is apparent from table 12 and 13 that only a small proportion of total elements are extractable except for Na and K. The EC values ranged from 1344 to 1835µS/cm at 25cm, while it ranged from1372 to 4950µS/cm at depth 45cm, this due to the continuous leaching of salts with the percolating water.

Elements concentrations gradually increase with depth, which show evaporation, dissolution of soil minerals and the effects of sludge used as fertilizers.

Table 40: Statistical analysis for water collected at 25 cm depth at QAA (WERSC, 1989).

Parameters	Minimum	Maximum	Mean	Standard Deviation
pH	7.23	8.3	7.765	0.41
EC µS/cm	1344	1835	1589.5	191.50
Na meq/l	6.7	10.6	8.65	1.46
K meq/l	0.0	0.4	0.2	0.15
Mg meq/l	2.3	3.7	3	0.57
Ca meq/l	3.2	4.2	3.7	0.36
Cl meq/l	8.2	9.75	8.975	1.35
NO3 meq/l	0.29	1.9	1.095	0.70
SO4 meq/l	1.36	3.3	2.33	0.64
HCO3 meq/l	3.25	3.56	3.405	0.12
TDS mg/l	837.4	1231	1034.2	147.45

Table 41: Statistical analysis for water collected at 45 cm depth at QAA (WERSC, 1989).

Parameters	Minimum	Maximum	Mean	Standard Deviation
pH	7.05	8.46	8.07	0.46
EC µS/cm	1372	4950	2010.15	1254.72
Na meq/l	7.21	25.5	11.42	6.42
K meq/l	0.06	0.51	0.16	0.15
Mg meq/l	2.1	13.4	4.41	3.53
Ca meq/l	2.63	13	4.74	3.27
Cl meq/l	5.46	38.5	11.46	11.14
NO3 meq/l	0.01	2.3	1.43	0.83
SO4 meq/l	1.24	8.87	3.1	2.40
HCO3 meq/l	2.44	6.98	4.53	1.52
TDS mg/l	859.5	3081	1367.09	742.10

The increase in salinity, and in the EC; is due to the dissolution of carbonate minerals and halite. High EC values are usually indicated by high values of elements such Na, Ca, Mg and K.

The gradual increase with depth in the concentrations of Ca and Mg and the strong decrease in HCO_3 is an indication of precipitation of carbonates and ion exchange in the clays within the soil matrix. This increase is compatible with the increase in Cl and Na ions at depth of 45cm.

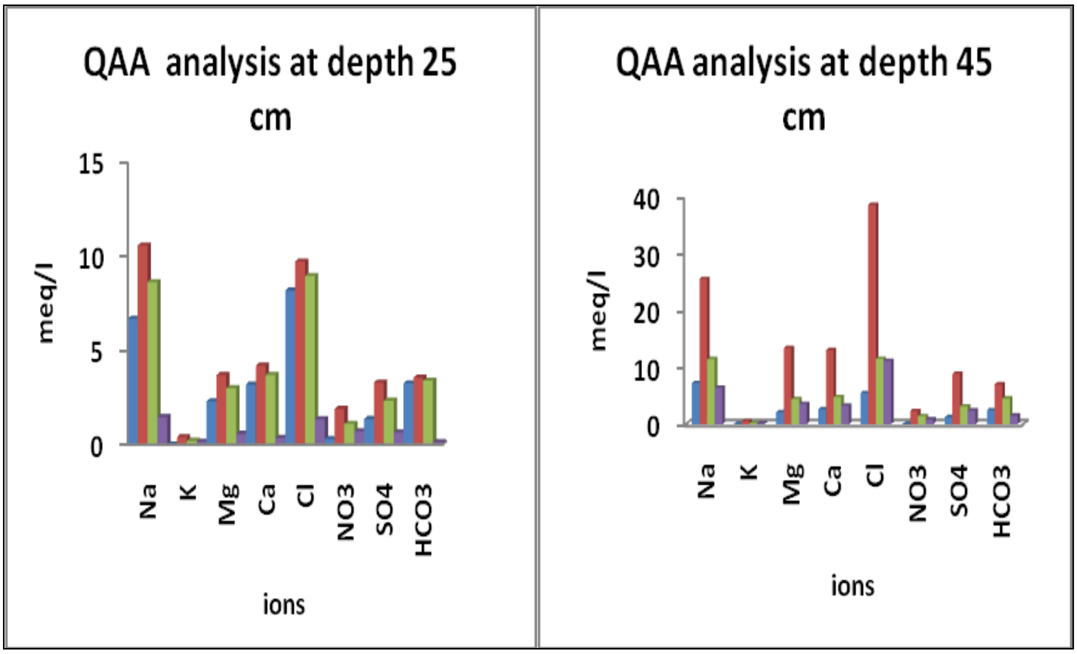


Figure 59: Bar diagram showing the chemical analysis of the applied water and its changes with depth in QAA test site.

7.5 Saturation indices (SI)

The potential for chemical reaction to take place during infiltration can be determined by the chemical equilibrium of the water with the mineral phases. One of the procedures to determine the equilibrium state of water with a mineral phase is by calculating the saturation index (SI).

Saturation index (SI) is defined as:

$$SI = \log (IAP/Keq)$$

IAP: Ionic Activity Product.

Keq: mineral equilibrium constant at a given temperature (Drever 1998).

If SI is equal zero then the water is in equilibrium with respect to the mineral phase, and if the value of SI is negative (less than zero) the water is under saturated with respect to the mineral phase and it will dissolve the mineral phase to reach the equilibrium state, and if SI is positive (greater than zero) the water system is over saturated and mineral precipitation is possible.

The SI for the water samples in the test sites was calculated using the laboratory and field measurements and using Aquachem software. The calculated values for the different test sites for the most common minerals phases of samples of calcite, halite, aragonite, gypsum, anhydrite and dolomite are given in table (42).

7.5.1 Calcite SI:

The distribution of calcite **SI** is shown in figure (60). Mainly the water samples of farm 1 and farm 2 are under saturated with respect to calcite. The water has the potential to dissolve calcite from the soil.

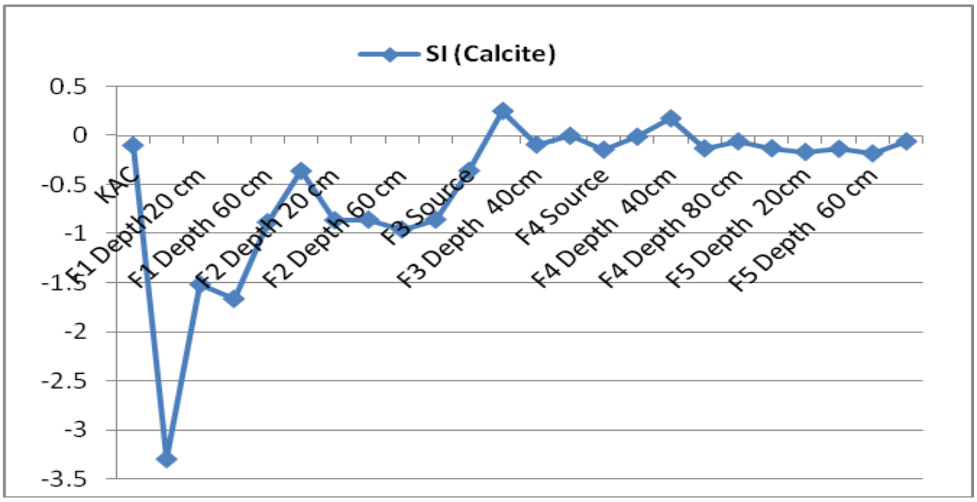


Figure 60: Saturation index for calcite in the soil water samples of the different test sites.

Some samples show SI values near saturation as a result of evaporation and ion concentration, such as the water samples at farm 3 at depth of 20 cm and depth of 40 cm and farm 4, which are over saturated and tend to precipitation calcite at their respective depths. But such precipitation processes take a long time and the equilibrium sate becomes reversed upon re-irrigation.

7.5.2Aragonite SI:

All water samples are found under saturated with respect to this mineral, and they are capable to dissolve aragonite from the testing sites. Thus values of SI aragonite in farm 3 and farm 4 show saturated saturation. But as irrigation water is added they again become under saturated.

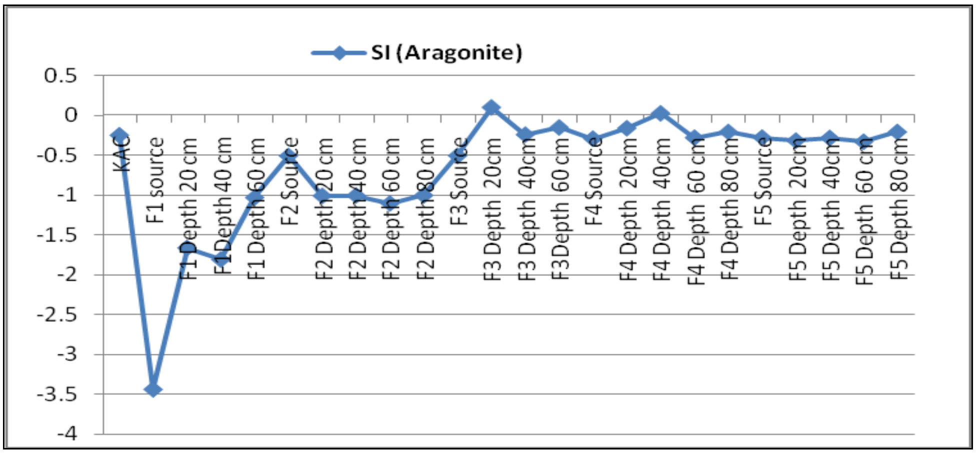


Figure 61: Saturation index for aragonite of the soil water samples in different test sites.

7.5.3Halite SI:

Generally the main source of Na and Cl in water samples is halite dissolution. The water used in irrigation has negative values of SI (under saturated), which gives strong indicator for dissolution of soil halides. Evaporation may cause high Cl and Na concentrations but it does not reach a saturation state.

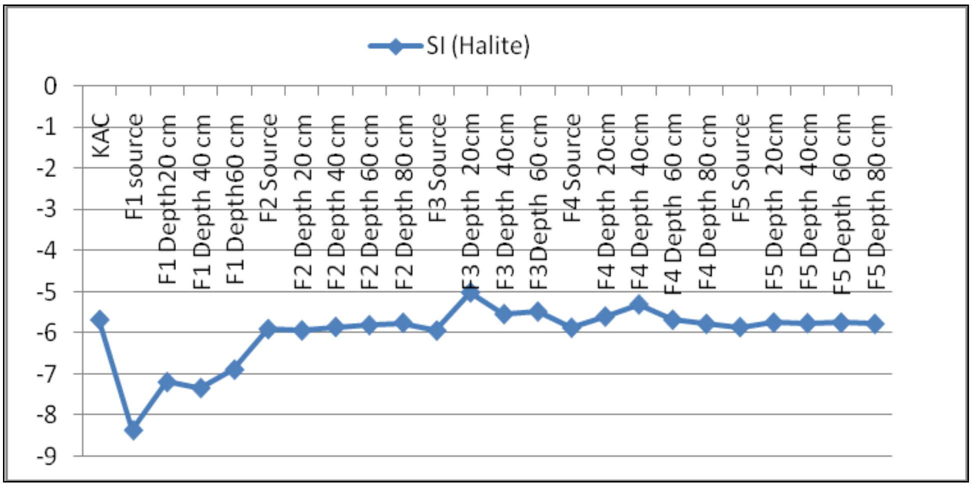


Figure 62: Saturation index for halite of the soil water samples in different test sites.

7.5.4 Gypsum SI:

All waters samples were undersaturated with respect to gypsum and hence dissolution of soil gypsum is possible, Figure (63).

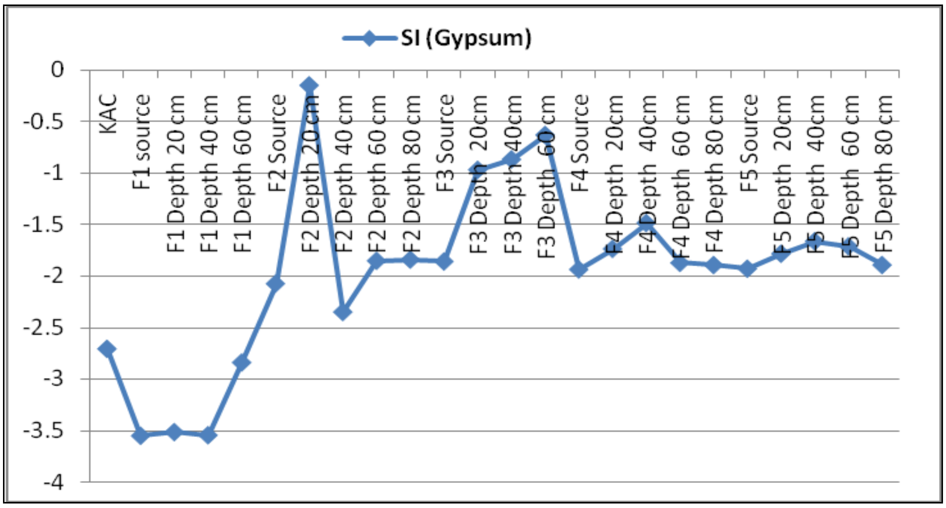


Figure 63: Saturation index for gypsum of the soil water samples in different test sites.

7.5.5 Anhydrite SI:

All samples are undersaturated with anhydrite and dissolution of soil anhydrite is possible figure (64).

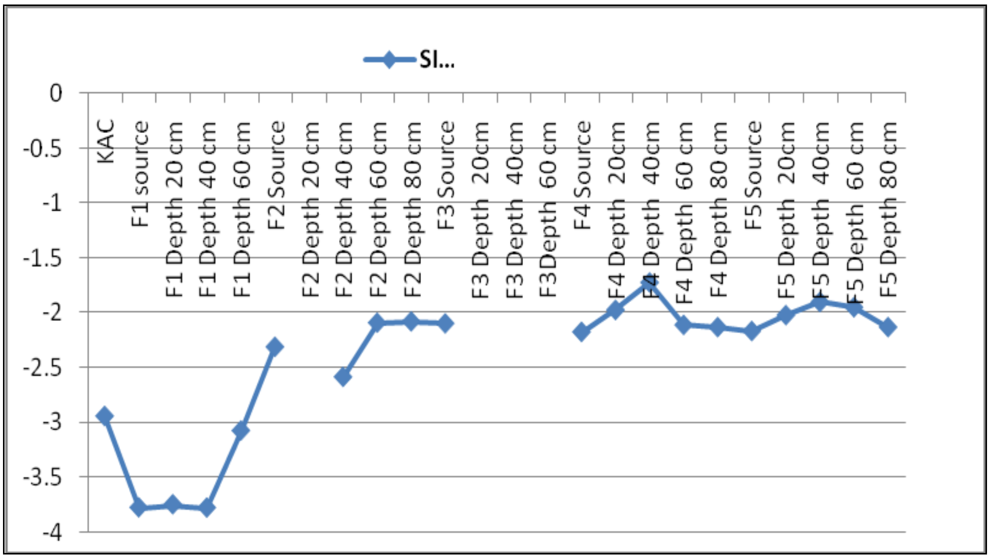


Figure 64: Saturation index for anhydrite of the soil water samples in different test sites.

7.5.6 Dolomite SI:

The saturation state of dolomite is similar to that of calcite. It temporarily shows over saturation, but without precipitation of dolomite (farm 3).The over saturated state ends when the soil in re-irrigated. Figure (65) shows the spatial variation of dolomite SI of the soil water samples, that there is a more saturated status in farm 3, but the main trend is towards under saturated zone in the different farms.

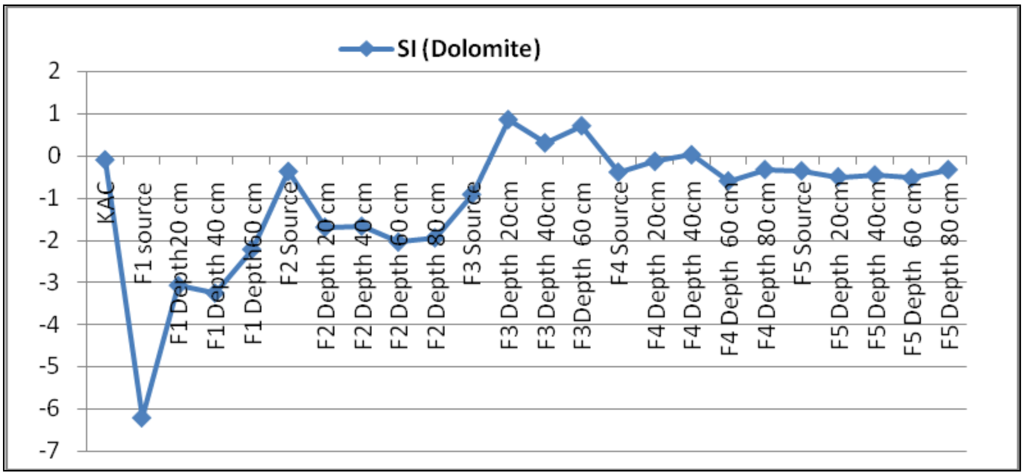


Figure 65: Saturation index for dolomite of the soil water samples in different test sites.

The results show that all the samples are undersaturated with respect to anhydrites, Gypsum and Halite and capable of dissolving these minerals from the soil content.

This means that no deposition of these minerals in the soil profile is taking place which might cause logging and lower permeability.

Table 42: Saturation index for the water sources and the soil water at different depth in different farms in study area (Deir Alla).

Station ID	SI (Anhydrite)	SI (Aragonite)	SI (Calcite)	SI (Dolomite)	SI (Gypsum)	SI (Halite)
KAC	-2.9446	-0.2491	-0.1016	-0.0942	-2.7079	-5.6821
F1 source	-3.78	-3.4401	-3.2927	-6.2188	-3.55	-8.3576
F1 Depth 20 cm	-3.7514	-1.6635	-1.5161	-3.0738	-3.5143	-7.1909
F1Depth 40 cm	-3.7816	-1.8097	-1.6623	-3.2573	-3.5444	-7.3349
F1 Depth60 cm	-3.0773	-1.0314	-0.884	-2.2226	-2.8403	-6.8878
F2 Source	-2.3126	-0.509	-0.3615	-0.3705	-2.0759	-5.9059
F2 Depth 20 cm	N.A	-1.0102	-0.8628	-1.6953	-0.154	-5.938
F2 Depth 40 cm	-2.5869	-1.0045	-0.857	-1.6696	-2.3501	-5.8546
F2 Depth 60 cm	-2.0913	-1.1049	-0.9575	-2.0469	-1.8545	-5.8102
F2 Depth 80 cm	-2.0799	-1.0041	-0.8567	-1.9468	-1.8431	-5.7541
F3 Source	-2.0979	-0.5069	-0.3595	-0.9166	-1.8612	-5.9417
F3 Depth 20cm	N.A	0.1003	0.2478	0.8595	-0.9721	-5.0161
F3 Depth 40cm	N.A	-0.2409	-0.0934	0.3072	-0.871	-5.5439
F3Depth 60 cm	N.A	-0.1511	-0.0036	0.7115	-0.6348	-5.4794
F4 Source	-2.1753	-0.2927	-0.1453	-0.3882	-1.9385	-5.8737
F4 Depth 20cm	-1.9752	-0.161	-0.0135	-0.132	-1.7385	-5.6035
F4 Depth 40cm	-1.7243	0.0259	0.1734	0.0258	-1.4878	-5.308
F4 Depth 60 cm	-2.1114	-0.2795	-0.1321	-0.5949	-1.8747	-5.6794
F4 Depth 80 cm	-2.1317	-0.2079	-0.0605	-0.3264	-1.895	-5.7797
F5 Source	-2.1676	-0.2784	-0.131	-0.3558	-1.9309	-5.8596
F5 Depth 20cm	-2.0222	-0.316	-0.1686	-0.4986	-1.7854	-5.7484
F5 Depth 40cm	-1.9021	-0.2833	-0.1358	-0.4531	-1.6653	-5.7633
F5 Depth 60 cm	-1.9506	-0.3307	-0.1833	-0.5265	-1.7139	-5.7512
F5 Depth 80 cm	-2.1317	-0.2079	-0.0605	-0.3264	-1.895	-5.7797

KAC: King Abdullah Canal, F: farm, N.A: not analyzed.

8 Conclusion and Summary

Recently, the wastewater treatment at Khirbet Es-Samra (KS) has been changed from stabilization ponds type of treatment to a mechanical type. The quality of the effluents changed dramatically to the better. The characteristic of the effluents water of KS mechanical treatment indicates that the average BOD_5 concentration ranged from 6.5 to 7.5 mg/l, which is lower than the allowable Jordanian standards of 30 mg/l for wastewater discharges. Similar result for COD, NO_3^-, PO_4^{-3} and pH were also obtained. The KS mechanical treatment plant proved to be highly efficiency in respect to BOD, NO_3, pH and COD removal.

The water quality and pollution loads in the basin are therefore set to improve. The water quality in Zarqa River and KTD is affected strongly by treated systems of KS WWTP. Such actions, has and is creating benefits for the ecosystems associated with the river and KTD water, for the well being of the people of the basin and for the economy of framers along Wadi Zarqa and the Jordan Valley areas irrigated with KTD water.

The chemical and physical parameters were measured and analysed in seven sites along Wadi Dhuleil and Zarqa River to King Talal Dam. There are major changes in the pH values between the effluents of old treatment plant and the modern one. pH values of KS effluents ranging from 7 to 7.24 when discharging into the recipient water body. Zarqa River pH values of all the sampling sites along the River course during the observation period varied from 7.41 to 8.46 in summer, 6.46 to 8.47 in autumn, 7.57 to 7.75 in winter and 7.14 to 8.3 during spring. Along the River course slight increases have taken place in the pH values due to algal activity. In KTD, the pH values ranged from 5.68 to 8.54. This indicates that the increase is mainly caused by the increasing in the bicarbonate concentration.

No major changes have taken place in the salinity of the effluents of KS along Zarqa River course. This is understandable because KS is not supposed to treat any salinity parameter. The EC of the different sites ranged from 1772 to 3090µS/cm. The changes increase or decreases in the salinity of the Zarqa River reflect the effects of rainwater (floods) and the discharges of groundwater seepages an springs.

Decrease of most cations along the river indicated the dilution effect by fresh surface and groundwater along the river course. Na^{+} concentration ranged from 6.3 to 16.7 meq/l, Mg^{+2}concentrations from 1.2 to 4.8 meq/l, Ca^{+2} concentration ranged from 2.8 to 13.9 meq/l during observation period. The Ca^{+2} and Mg^{+2} concentration increase along the river, this increase is attributed to reactions of the water with the carbonates of the riverbed. The K^{+} concentrations along the river course ranged from 0.62 to 2.3 meq/l.

Decreases of most anions along the river was observed, Cl^{-} concentration for sites ranged from 8.9 to 17.2 meq/l. The PO_4^{-3} concentration shows a decreasing pattern from KS downstream to Jarash Bridge. It ranged from 0.01 to 0.1 meq/l along the river course; the decrease in the concentration along the river course indicates the phosphate uptake by aquatic plants. While the high concentration of PO_4^{-3} in King Talal Dam reached maximum values in spring and summer times and ranged from 0.06 to 0.19 to 1.63meq/l, contributing to its high eutrophication process.

The NO_3^{-} concentration increased along the river course gradually to a concentration ranging from 0.1 to 1.10 meq/l. The low concentration of soluble nitrate in KS effluent is indicative of a well functioning anaerobic biodegradation (denitrification), nitrate uptake by algae with downstream flow and with more oxygenation of the water. More nitrates are formed as a result of increased microbial oxidation of ammonium (nitrification). While the NO_3^{-} concentration increases in KTD and range

from 0.23 to 1.14 meq/l. This increase is caused by the continuous action of nitrification processes.

The SO_4 concentration decreases rapidly along the river course and ranged from 0.18 to 2.72 meq/l in the effluent of KS, the concentration at Jarash Bridge decreases to around 2.16 to 1.12 meq/l. The concentration in the KTD water ranges from 0.98 to 1.83 meq/l. Aerobic decomposition and oxidative processes caused by microorganisms in the dam to contribute the decreasing SO_4^{-2}concentration of water.

The HCO_3 concentration along the river course ranges from4 meq/l to 11.7 meq/l. The production of H_2S due to anaerobic processes allows the CO_2 gas to escape with the results of lowering the HCO_3 content of the water along river.

The COD values ranged from 36.8 to 52.2 mg/l in the treated water discharged into the river course. The COD values ranged from 83 to 361mg/l in Site III, 22 to 82 mg/l in Site IV, 20 to 182mg/l in Site V and ranged from 24 mg/l to 749 mg/l in Site VI. COD in King Talal Dam water shows a minimum value of 19.49 mg/l in March 2010, while a maximum value of 48 mg/l was measured in June 2010. As a result of this analysis a decrease in COD values has been measured throughout the Zarqa River and in KTD. This was a major direct result of the improved treatment in Samra wastewater treatment plant.

The BOD concentrations along the river from the outlet of KS to the King Talal Dam are within the allowable Jordanian standard. The new KS effluent contain low concentration of BOD because of its high efficiency, with positive impacts on the water quality of Zarqa River, King Talal Dam and lands irrigated with their water. The effluents of the new wastewater treatment plant have BOD5 values ranging from 6.4 to 12.9 mg/l. The maximum BOD value was 25.7 mg/l in IV sampling site, while the minimum BOD value was 4.8 mg/l in the Site III. Along the river, as a result of self purification processes the BOD decreases from Site IV to Site V, because of

biological decay of the organic matter, the presence of algae which consumes the organics and the natural re-aeration enhancing the oxidation process.

The trace elements Pb, Mn, Co and Cu analyzed in water samples and were found to have very low concentrations of less than 0.01 ppm, Fe can be found in small concentration of 0.02 ppm.

The changes in water composition during infiltration were studied using suction cups at depths of 20, 40, 60 and 80 cm in the soil. Different water types and sources were applied in the test to determine the different changes in water chemistry which take place during the infiltration process into the aquifers.

Surface water (rainwater) increase in salinity during infiltration with increasing depth. The increase in the concentrations of the different parameters is a direct result of dissolution of soil minerals and evaporation from the top soil.

In the freshwater of the spring used for irrigation in Wadi Sir Plant nursery, the increase in EC and other parameters with depth can be attributed to evaporation and slight dissolution of soil minerals.

In Wadi Sir WWTP on comparing the chemistry of the applied water and that of the infiltrated water at depths of 20, 40 and 60 cm, it was found that the EC increased at 20 cm depth, then it decreased at 40 cm depth 60cm depth the water salinity is therefore highest a depth of 20 cm and it decreases gradually with depth the collection of samples from the different depths extends over a time period of an average of around 72 hours after irrigation. Therefore, the first two depths 20 and 40 cm remain under the effects of irrigation and evaporation and may show higher or lower salt contents.

The concentrations of different ions increase in the soil water due to evaporation from the soil surface. In Fuheis WWTP the increase in salinity is a mere result of salt dissolution from the soil profile and the downward movement with the down

percolating water. Added to that, the salts accumulated in the topsoil as a result of evaporation, their dissolution and downward movement with the infiltration water which contributes to the salinity of the water at depth.

Different impacts affect the development of soil salinity and degradation of infiltration water into groundwater bodies, these impacts are:

1. Composition of irrigation water.
2. Type of irrigation; furrow, drip, subsurface or sprinkler.
3. Evaporation, protected (green house), mulch or open to climatic effects.
4. Type of applied irrigation water.

The results of suction cup tests applied on a variety of soil types, using different water compositions and testing different climatic conditions show the following:

1. As long as generous excess irrigation is used soils and groundwater will only be affected by the type of applied water. Because the same applied percolate down to the groundwater.
2. Low permeability soils tend to accumulate salts as results of evaporation and plant up take of minerals.
3. Protected irrigation water application (green house, mulch and subsurface irrigation) save soil water from evaporation and does not allow salts to concentration in soils or in the infiltrated water to the groundwater.
4. Plant uptake of soil water chemicals cause decreases in some soil water constituents such as NO_3, PO_4, K, Na, Cl etc. and may conserve others. Therefore crop water requirements on irrigation water should be applied to soils, but at the same time evaporation from irrigated and transpiration losses must be minimized by the use of green house, mulches, drip or even subsoil irrigation.

8.1 Salinity

The electrical conductivity (EC) of the infiltrated water, which was extracted from different depths, increased gradually from the top of the soil to the depth of 60 cm due to the slight dissolution processes of soluble minerals within the soil. An exception was found when soils were continuously under irrigation.

The changes taking place during the infiltration of treated wastewater show that the NO_3 and PO_4 ions decreased with depth, as a result of plant up take and transformation of NO_3.

The main salt in the JV is halite (NaCl), with important salinity impacts and osmotic effects or toxic effects. Most tree crops sensitive to high concentration of Cl^- such citrus, grapes, avocado, strawberries and some ornamentals. While vegetable crops such tomatoes and cucumbers are not much sensitive.

The effect of sodium on clay particles takes place in two stage; dispersion and swelling so the soil becomes puddle, resulting in reduced infiltration and permeability. The effect of sodium is not a direct effect on plant but on the physical properties of soil which affects plant growth and that has to do with the water movement in the soil. In normal productive soils, the predominant exchangeable cation is calcium which has effects on the soil physical properties. Calcium tends to enhance the aggregation of clay particles which results in desirable properties in water infiltration, permeability and aeration.

8.2 Water type

Natural waters contain some dissolved salts in different concentrations. In the absence of leaching, salts accumulate in a proportion to the salt content of the water and the amount of the applied water. In this study different applied waters were used as

indicator of changes taking place during infiltration. Fresh waters or water with low salts content show increases in salt concentration with depth.

Conditions, such as composition of soil, capillary force evaporation cause the increase in the salt concentrations.

Precipitation water has generally pH values of more than 5.6 after outranging events of some 50 mm when dust is removed from the atmosphere, therefore, no acid rain occurs in Jordan.

The alkalinity of precipitation water expressed as pH increases during infiltration. In average, dissolved solids concentration increases from the top soil downward as a result of water rock interaction.

KAC water used in irrigation show increases in the different salinity parameters of Na, K, Ca, Mg, SO4, Cl and HCO3.

8.3 Crops

Wastewater is a rich source of plant nutrients its impacts on yields vary from crop to crop. If crops are undersupplied with essential plant nutrients, wastewater irrigation will act as supplemental source of fertilizers, thus increasing crop yields. But if nutrients delivered through the wastewater are in oversupply, yields may be negatively affected.

8.4 Soils

Impact of treated wastewater use in irrigation on agricultural soil is mainly the presence of high nutrient contents (Nitrogen and Phosphorus),and the SI calculation shows the high process of dissolving minerals increasing the Na, Cl, Ca and other salts which are added to the soil over time. Wastewater can also contain salts that may accumulate in the root zone with possible harmful impacts on soil health and crop yields.

The main effect of water use in irrigation on soils is the increasing salinities of the soil due to evaporation and dissolution or precipitation of soil minerals.

The results of tests in the different test sites show that water/solid matrix interactions are limited and no adverse dissolution precipitation of minerals are taking place. This is due to frequent irrigation and relatively high soil permeability.

8.5 Ground water

Infiltration to the groundwater may affect the quality of the groundwater, by increasing the salts contents with depth.

The main impact depends on a host of factors including depth of water table, quality of groundwater, quality of source water, soil drainage, scale and frequency of irrigation.

The results of testing show that the infiltration water beyond a depth of 80 cm shows higher salt contents, but it has not drastically increase in salinity due to plant uptake of the different dissolved cations and anions, especially nitrates and phosphates.

9 Recommendation

1) Discharges of water into the Zarqa River should undergo suit analyses in order to protect that important surface water source in Jordan.

2) Establishment of activities such as industrial plants should undergo very strict environmental impact EIA concerning their effects on surface and groundwater resources.

3) Prevent any discharges from factories along the river course before proper treatment of these effluents in order not to cause any detriment to the quality of the River water, to King Talal Dam or to irrigation water originating from Zarqa River and used in Jordan Valley.

4) It is time to study the bearing capacity of the system Zarqa River, King Talal Dam and lower Zarqa River for the different pollution parameters taking into proper consideration the self-purification capacity of the River-Dam system.

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11 Appendices:

Appendix A

Appendix B

Appendix A:

Table 43: The Values of measurements effluent quality of Khirbet As Samra in 1989; source: The Water and Environmental Research and Study Centre in Jordan University (WERSC).

Parameter	T ˚C	EC µS/cm	pH	NO3 meq/l	HCO3 meq/l	SO4 meq/l	Cl meq/l	Ca meq/l	Mg meq/l	Na meq/l	K meq/l	COD mg/l	PO4 meq/l	BOD mg/l
Jan-1989	10.8	2130	10.8	0.35	13.6	1.35	5.9	2.9	3.38	4.74	0.58	480	1.01	103
Feb-1989	11	1740	7.5	0.49	12.46	0.95	7	3.3	2.9	7.63	0.82		0.85	98
Apr-1989	16.5	2170	7.57	0.4	12.46	1.064	7	3.4	2.8	10.07	0.24	247.9	0.19	152
May-1989	17.8	1950	7.3	0.54	14.4	1.2	8.87	3.7	3.9	9.2	0.98	289.4	0.26	132
Jun-1989	23.4	2370	7.73	0.29	15.3	1.58	10.7	5.4	3.6	9.96	1.15		0.79	113
Jul-1989	25.6	2480	7.85	0.075	13.6	0.85	11.16	6.2	4.5	11.15	1.2	262	0.79	60
Aug-1989	26.2	2430	8.09	0.27	14.3	3.04	10.6	3.8	4.038	6.71	1.17	117	0.59	83
Sep-1989	26.8	2410	742	0.52	11.7	1.76	11	3.2	5	13.87	1.23	1204.8	0.67	60
Oct-1989	22	2360	8.17	0.3	13.02	0.68	10.7	4.24	4.23	10.15	0.97	244.7	0.44	120
Nov-1989	14.4	2620	8.07	0.35	12.67	2.36	11.4	4.7	3.8	9.93	1.02	341.07	0.72	100
Dec-1989	10.5	2410	7.96	0.4	12.27	1.27	9.2	3.7	3.6	9.06	1.13	268.5	0.803	90

Table 44: The Values of measurements effluent quality of Khirbet As Samra in 1990; (WERSC).

Parameter	T ˚C	EC µS/cm	pH	NO3 meq/l	HCO3 meq/l	SO4 meq/l	Cl meq/l	Ca meq/l	Mg meq/l	Na meq/l	K meq/l	COD mg/l	PO4 meq/l	BOD mg/l
Jan-1990	9.9	2320	7.9	0.36	13.37	0.65	10.2	4.1	3.2	9.39	1.02	316.9	0.96	188
Apr-1990	21	2040	7.79	0.76	12.26	0.88	8.4	3.6	3.1	10.59	1.02	1232.5	0.57	158
Jun-1990	22	2600	6.7	0.8	7.74	0.78	12.6	4.2	4.2	11.63	1.1	487.3	1.31	141
Aug-1990	26.1	2530	7.7	0.31	14.01	0.84	13.86	3.95	4.04	12.2	1.21	229.8	0.89	110
Sep-1990	24.7	7.98	2610	0.469	10.61	1.28	11.4	4.2	4.2	11.52	1.28	238.5	0.21	107
Oct-1990	19.2	2700	8.13	0.28	15.16	1.53	10.2	4.66	3.8	11.8	1.15	283.4	0.57	70
Dec-1990	15	2840	8.07	0.55	15.3	0.94	11.36	4.32	4.95	11.77	1.09	348.2	0.65	100

Table 45: The Values of measurements effluent quality of Khirbet As Samra in 1991; (WERSC).

Parameter	**T °C**	**EC µs/cm**	**pH**	**NO3 meq/l**	**HCO3 meq/l**	**SO4 meq/l**	**Cl meq/l**	**Ca meq/l**	**Mg meq/l**	**Na meq/l**	**K meq/l**	**COD mg/l**	**PO4 meq/l**	**BOD mg/l**
Jan-1991	12.1	2750	8.3	0.6	15.8	0.4	0.55	4.5	3.08	11.5	1.03	321.5	0.64	120
Feb-1991	16.5	2140	8.24	0.56	13.85	0.91	9.01	4	2	9.69	0.92	277.7	0.69	130
Mar-1991	20.6	3370	8.11	0.49								331.1		110
May-1991	23.2	2640	7.6	0.53	14.89	1.79	10.58	4.6	2.8	12.59	1.02	308.3	1.07	103
Jul-1991	26	2670	8.04	0.91	13.9	1.2	11.95	4.4	3.6	12.16	1.39	224.5	0.65	110
Aug-1991	25.9	2870	7.97	0.57	15.4	1.16	4.26	4.26	4.16	12.29	1.43	252.1	0.42	80
Nov-1991	26.5	2820	7.5	0.29	15.9	0.47	11.37	5.14	3.77	15.5	1.7	309.3	0.63	90
Dec-1991	18.6	2880	7.83				11.76			11.73	0.03		0.006	85

Table 46: The Values of measurements effluent quality of Khirbet As Samra in 1993, (WAJ, open files).

Parameter	**Unit**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**AV.**
Eff.Av.Flow	**m^3/day**	108022	110780	109985	108793	111947	107568	107879	108362	108533	108893	110647	111932	109422
DO-Eff.	**mg/L**							3.8	4.4	3.1	5.1	5.7	5.4	4.6
PH-Eff.		7	7	7	7	7	7	7.4	7.6	7.63	7.6	7.8	7.7	7.3
TDS-EFF.	**mg/L**							1286	1272	1264	1232	1244	1278	1262.7
BOD5-Eff.	**mg/L**	205	205	229	191	128	110	92	101	71	92	108	150	140.2
COD-Eff.	**mg/L**	431	450	452	434	341	288	301	304	303	280	318	417	359.9
S04-EFF.	**mg/L**							37	41	35.5	29	31	17	31.8
NO3-N EFF.	**mg/L**							0.1	1.2	0.1	0.7	5	0.7	1.3
CL-EFF.	**mg/L**								337	322		157.4	314	282.6

Table 47: The Values of measurements effluent quality of Khirbet As Samra in 1999, (WAJ, open files).

Parameter	**Unit**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**AV.**
Eff.Av.Flow	**m^3/day**	148664	145460	146980	141300	140267	139048	143148	140632	144290	150267	148312	151688	145005
PH-Eff.		7.9	8	8.1	8	8	7.8	7.7	7.83	7.7	7.9	7.95	8.25	8
TDS-EFF.	**mg/L**	1216	1112	1180	1188	1242	1314	1334	1334	1350	1256	1292	1276	1258
BOD5-Eff.	**mg/L**	145	161	145	149	95	92	96	102	92	106	111	118	118
COD-Eff.	**mg/L**	557	508	590	544	502	540	480	432	403	376	476	519	494
S04-EFF.	**mg/L**	40	34	27	16	22	32	33	33	38	47	29	19	31
PO4-P EFF.	**mg/L**	18.8	16.1	13.4			19.7		19.7		19.8		17	17
NO3-N EFF.	**mg/L**	0.21	<0.25	<0.25	<0.25	0.27	8.3	8.4	10.9	5	1.5	3.1	1.7	4
HCO3-EFF.	**mg/L**		859		946	952	824	804	782		860	897		866

Table 48: The Values of measurements effluent quality of Khirbet As Samra in 2000, (WAJ, open files).

Parameter	**Unit**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**AV.**
Eff.Av.Flow	**m^3/day**	160884	145662	146810	155179	151895	146764	138331	139746	150979	148042	150055	160725	149589
DO-Eff.	**mg/L**	5.5	5.1	4.2	2.8	3.5	3.8	2	2.1	2.3	2.9	3.35	4.6	4
PH-Eff.		805	8	7.8	7.68	7.6	7.75	8	7.95	8.1	8	8.16	8.1	8
TDS-EFF.	**mg/L**	1126	1108	1180	1182	1216	1270	1262	1378	1246	1240	1198	1238	1220
BOD5-Eff.	**mg/L**	142	140	162	122	149	123	126	117	139	149	127	174	139
COD-Eff.	**mg/L**	512	489	516	488	491	376	382	446	560	570	564	567	497
S04-EFF.	**mg/L**	37	44	32	10	17	62.2	32	38	32	36	9.1	7	30
PO4-P EFF.	**mg/L**	13.6	17.9				12.6		15		17		21	16
NO3-N EFF.	**mg/L**	0.1	<0.25		<0.25		75	88.4	<0.1		83		<0.25	62

Table 49: The Values of measurements effluent quality of Khirbet As Samra in 2002, (WAJ, open files).

Parameter	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AV.
Eff.Av.Flow	**m^3/day**	179982	152302	136164	139617	136423	135242	122341	128997	127787	128323	151291	150689	140763
DO-Eff.	**mg/L**	2.8	3.6	2.25	0.93	0.34	0.63	1.51	2.18	1.8	2.6	4.5	2.75	2
PH-Eff.		7.96	7.94	7.94	7.79	7.74	8.2	7.9	7.9	7.91	7.85	7.8	7.75	8
TSS-Eff.	**mg/L**	1064	962	1158	1100	1210	1248	1294	1332	1298	1222	1250	1150	1191
BOD5-Eff.	**mg/L**	172	191	213	93	122	100	110	113	100	112	114	183	135
COD-Eff.	**mg/L**	485	505	577	494	438	518	482	501	465	542	520	546	506
S04-EFF.	**mg/L**	20	26	9.6	7.5	9.6	19	25	27	23	37	10.7	16	19
PO4-P EFF.	**mg/L**		18.7		15	0	4.6		9.35		9.4			10
NO3-N EFF.	**mg/L**	0.1	<0.5	<0.27	<0.5	<0.27	0.14		<0.08		<0.27			0

Table 50: The Values of measurements effluent quality of Khirbet As Samra in 2004 analysis (WAJ, open files).

Parameter	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AV.
Eff.Av.Flow	**m^3/day**	179982	152302	136164	139617	136423	135242	122341	128997	127787	128323	151291	150689	140763
DO-Eff.	**mg/L**	2.8	3.6	2.25	0.93	0.34	0.63	1.51	2.18	1.8	2.6	4.5	2.75	2
PH-Eff.		7.86	8	8	8	8.14	8.15	8.06	8.1	8.12	8.15	8.18	7.93	8
TSS-Eff.	**mg/L**	62	89	89	110	127	115	124	122	114	124	73	73	102
BOD5-Eff.	**mg/L**	166	175	231	183	120	99	98	101	99	103	120	157	138
COD-Eff.	**mg/L**	-	-	-	622	531	854	459	302	432	475	605	690	552

Table 51: The Values of measurements effluent quality of Khirbet As Samra in 2005 analysis (WAJ, open files).

Parameter	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AV.
Eff.Av.Flow	**m^3/day**	160431	156338	142619	149578	136117	133269	157889	152323	144855	145454	152510	163353	149561
DO-Eff.	**mg/L**	2.3	3.13	2.72	3	2.3	2.5	3	-	-	-	-	-	3
PH-Eff.		7.88	7.93	8.14	8.21	8.1	8.1	8	-	-	-	-	-	8
TSS-Eff.	**mg/L**	67	79	96	98	105	134	112	106	104	83	74	54	93
BOD5-Eff.	**mg/L**	165	198	195	146	126	130	103	139	123	141	218	240	160
COD-Eff.	**mg/L**	642	708	554	677	540	481	543	523	482	657	636	590	586

Table 52: The Values of measurements effluent quality of Khirbet As Samra in 2007, (WAJ, open files).

Parameter	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AV.
Eff.Av.Flow	**m^3/day**	169397	186862	108909	113460	80370	61491	34604	56461	23357	29503	28089	50630	78594
PH-Eff.		7.9	7.56	7.78	7.64	7.82	7.76	7.81	7.74	7.79	7.71	7.7	7.71	7.76
BOD5-Eff.	**mg/L**	227	240	151	135	88	84	86	135	118	133	124	200	143
COD-Eff.	**mg/L**	834	619	579	680	497	548	950	503	430	559	190	360	562

APPENDIX B:

Table 53: Chemical and physical analyses for (Pipes Factory) Site III in 1989, 1990 and 1991**.**

Parameter	T ˚C	EC µs/cm	pH	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	CL meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Jan-1989	23	2950	7.6	11.56	9.93	2.26	5.8	9	3.4	1.34	13.4	2.6		1888
Feb-1989	24	2430	7.15	12.9	7.3	0.1	4.2	7.6	2.13	1.4	13.1	0.012		1555.2
May-1989	27	2430	7.6	12.6	7.6	0.72	3.6	7.2	2.45	1.94	12.9	0.09		1555.2
Jun-1989	24.8	2750	7.38	13.5	5.3	0.217	4.6	3.13	6.34	1.33	13.7	0.71		1760
Jul-1989	33.2	3070	7.38	12.5	10.8	0.87	6.3	11.7	4.6	1.22	12.2	0.897	45.85	1964.8
Aug-1989	24.9	3120	7.61	11.91	10.05	0.16	9.8	10.7	2.9	2.24	14.5	4.57	10.07	1996.8
Sep-1989	24.5	3140	6.9	12.9	10.6	0.26	5.1	10.6	2.2	1.56	13.2	0.156	10.04	2009.6
Oct-1989	23	3250	7.71	15.9	9.3	1.21	5.1	9.8	4.8	1.49	16.2	0.019	34.11	2080
Nov-1989	23.5	3420	7.98	14.6	9.85	2.15	4.8	12.6	3.6	1.24	15.3	0.102	12.18	2188.8
May-1990	25	3000	7.25	13.8	8.5	1.84	5.2	10.3	3.2	1.45	14.9	0.134		1920
Jun-1990	18.3	3370	7.53	14.7	11.3	1.1	5.9	11.9	3.7	0.89	15.6	0.45	29.23	2156.8
Aug-1990	26.4	3150	7.3	11.13	10.8	2.1	7.4	12.2	5.49	1.44	12.7	0.012		2016
Sep-1990	25.4	2520	8.57	11.78	7.8	1.33	4.4	10.73	1.51	0.51	11.58	0.95	216.75	1612.8
Oct-1990	24.5	2600	8.25	10.3	8.9	1.01	5.4	13.6	1.28	0.23	10.45	0.48	231.6	1664
Nov-1990	21.4	2700	8.17	11.74	8.9	1.13	4.66	12.9	0.94	0.75	11.8	0.47	254.1	1728
Dec-1990	15.8	2840	8.08	11.5	9.87	2.65	4.22	14.7	0.94	0.5	11.68	0.43	316.2	1817.6
Jan-1991	10.9	2720	8.2	10.1	10.68	0.98	4.9	14.6	1.25	0.65	10.26	0.417	331.3	1740.8
Feb-1991	17.3	2140	8.24	10.5	5.9	1.025	3.6	9.2	0.48	0.47	10.6	0.402	282.8	1369.6
Mar-1991	20.5	2290	7.78	11.1	6.2	1.76	3.9	10.7	0.6	0.47	10.5	0.37	302.1	1465.6
May-1991	23.2	2870	7.82	13.3	7.9	1.76	4.7	12.8	0.64	0.57	13.8	0.39	242.1	1836.8
Jun-1991	26.1	2650	6.55	12.65	7.32	1.32	4.6	11.5	0.77	0.89	12.87	0.66	146.2	1696
Jul-1991	26	2670	8.04	12.16	9.4	1.39	3.6	11.3	1.59	0.91	12.6	0.42	224.5	1708.8
Aug-1991	27.2	2600	8.04	11.64	8.3	1.43	4.25	11.59	1.25	0.53	11.81	0.52	233.4	1664
Sep-1991	24.3	2685	7.95	11.5	9.63	1.18	4.35	13.2	0.47	0.29	11.86	0.43	290.7	1718.4
Oct-1991	26.2	2820	7.58	13	9.75	1.6	3.57	14.1	0.514	0.256	12.73	0.203	247.4	1804.8

Table 54: Chemical and physical analyses for (Nimra Bridge) Site IV in1989, 1990 and 1991.

Parameter	**T ˚C**	**EC μs/cm**	**pH**	**Na meq/l**	**Ca meq/l**	**K meq/l**	**Mg meq/l**	**HCO3 meq/l**	**SO4 meq/l**	**NO3 meq/l**	**CL meq/l**	**PO4 meq/l**	**COD mg/l**	**TDS mg/l**
Jan-1989	24	1820	7.84	11.7	3.5	0.64	2	2.871	1.07	0.8	10.58	1.87		1164.8
Feb-1989	23	1510	6.78	10	2.8	0.45	1.9	3.367	0.87	0.8	9.85	0.011		966.4
May-1989	25	1485	7.79	9.7	2.5	0.215	2.1	3.7	0.91	0.84	9.3	0.03		950.4
Jun-1989	24.6	1720	7.52	10.38	4.9	0.183	2.9	3.03	1.98	0.82	10	0.69		1100.8
Jul-1989	24.4	1837	7.54	10.27	4.7	0.05	3.4	4.3	2.01	0.571	10.87	1.07		1175.68
Aug-1989	24.7	1828	7.62	10.1	4.13	0.13	3.9	2.83	3.7	0.797	10.8	0.058	49.62	1169.92
Sep-1989	25.3	1870	7.56	9.8	5	0.205	3.6	4.1	3.46	0.86	10.23	0.043	10.04	1196.8
Oct-1989	22	1880	7.67	10.9	4.52	0.15	3.32	3.24	3.74	0.81	11.1	0.018		1203.2
Nov-1989	23.1	1980	7.55	10.9	4.5	0.34	3.2	4.3	2.9	0.81	11.4	0.073	14.37	1267.2
Dec-1989	22.9	1800	7.61	9.87	4.6	0.18	3.5	3.9	2.72	0.88	10.6	0.062		1152
Jan-1990	19.8	1770	7.56	8.17	4.61	1.18	3.36	3.8	2.62	0.98	9.87	0.087		1132.8
Aug-1990	26.3	1703	7.54	10.85	3.4	0.87	1.9	2.22	1.98	0.77	11.7	0.28		1089.92
Sep-1990	24.7	1800	7.95	9.73	4.2	0.18	3.8	4.5	2.23	0.79	10.35	0.063	6.69	1152
Mar-1991	24.3	2000	7.2	11.9	4.1	0.1	3.6	5.8	1.53	1.042	11.76	0.106		1280

Table 55: Chemical and physical analyses for (Tawaheen El Edwan) Site V in 1989 and 1991.

Parameter	T ˚C	EC µs/cm	pH	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	CL meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Jul-1989	26.4	2200	8.11	10.73	5.3	0.79	5.1	8.57	1.76	0.595	10.96	0.12	123.4	1408
Oct-1989	26.9	2390	7.92	11.12	6.75	1.13	4.12	10.14	2.24	0.61	10.62	0.32	135.2	1529.6
Nov-1989	22.5	2460	8.05	12.5	6.9	0.77	4.11	9.2	2.18	1.06	11.9	0.09	166.6	1574.4
Dec-1989	18.5	2640	8.03	14.6	6.4	1.09	4.72	11.2	1.33	0.83	13.1	0.17	193.5	1689.6
Jan-1991	15.6	2560	8.5	10.97	9.1	0.97	3.29	11.43	1.05	0.94	11.07	0.16	185.2	1638.4
Feb-1991	19.7	2220	8.05	10.9	6.8	0.66	3.8	9.99	0.87	0.63	10.42	0.21	56.53	1420.8
Mar-1991	23.8	2290	7.78	10.84	7.3	0.72	3.6	8.16	3.2	0.43	10.29	0.21	107.2	1465.6
Jun-1991	23.1	2500	6.4	13.2	5.4	1.23	4.6	9.58	1.28	1.27	12.15	0.42	73.1	1600
Jul-1991	28.1	2480	7.03	13.5	6.7	0.98	3.8	8.9	1.44	1.43	12.35	0.31	99.78	1587.2
Aug-1991	28.9	3950	7.93	21.63	10.75	1.02	4.87	11.62	2.89	0.83	22.5	0.31	154	2528
Sep-1991	24.4	2560	7.78	13.56	6.33	0.87	3.96	10.3	1.58	0.4	12.3	0.36	188.9	1638.4

Table 56: Chemical and physical analyses for (Jarash Bridge) Site VI in 1989, 1990 and 1991.

Parameter	T ˚C	EC µs/cm	pH	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	CL meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Jan-1989	18.8	1100	7.78	7.34	2.93	0.419	1.19	3	0.81	0.39	7.59	0.03	676	704
Feb-1989	17	1520	8.2	7.2	4.7	0.43	2.7	4.4	1.76	0.52	8.2	0.18		972.8
May-1989	30	1765	7.72	9.83	3.9	0.67	3.2	5.2	1.4	1.08	9.95	0.14	82.6	1129.6
Jun-1989	28.2	2170	7.87	10.9	5.6	0.826	4.2	7.2	2.66	0.69	11.21	0.19		1388.8
Jul-1989	26.1	2220	7.82	10.9	5.72	0.761	5.4	9.12	0.83	0.73	11.78	0.2	90.1	1420.8
Aug-1989	29.5	2140	8.29	10.05	5.52	0.82	4.99	7.878	2.19	0.59	10.4	0.26	92.86	1369.6
Sep-1989	26.2	2120	7.72	10.7	5.8	0.46	4.5	6.69	2.55	0.599	11.2	0.24	301.2	1356.8
Nov-1989	17.7	2470	7.9	11.6	5.32	0.95	5.71	9.5	2.17	0.39	11.5	0.32	115.3	1580.8
Dec-1989	13.8	2220	7.97	11.5	5.52	0.72	4.53	6.45	3.58	1.25	11.12	0.1	57.72	1420.8
Sep-1990	27.1	2310	8.53	11.18	6.6	0.97	4.2	7.9	2.97	0.977	11.12	0.02	107.7	1478.4
Oct-1990	27.4	2350	8.09	11.4	6.37	0.88	4.94	8.63	3.11	1.14	10.44	0.34	135.2	1504
Nov-1990	22.3	2400	8.08	10.44	8.57	0.77	4.3	10.02	2.1	1.47	10.32	0.11	137.2	1536
Dec-1990	17.5	2600	8	14.16	6.17	1.02	4.3	9.18	1.55	1.32	13.6	0.2	140.2	1664
Jan-1991	12.1	2480	8.02	12.3	6.97	0.92	4.15	9.4	1.28	1.52	11.97	0.16	148	1587.2
Feb-1991	19.8	2130	8.34	9.96	5.2	0.66	4.2	7.96	1.41	0.59	9.21	0.14	65.6	1363.2
Mar-1991	27.1	2680	1.42	11.64	6.8	0.71	4.8	8.56	1.19	1.42	11.76	0.36	99.4	1715.2
Jun-1991	20.8	2440	7.18	11.4	7.5	0.91	4.7	9.58	1.88	1.19	11.6	0.17	24.4	1561.6
Jul-1991	28.7	2400	7.61	12.3	6.6	0.98	4.3	7.34	1.74	2.21	12.58	0.27	54.88	1536
Aug-1991	17.8	2790	7.99	14.2	6.53	1.02	4.95	9.4	1.78	1.04	13.68	0.33	66.25	1785.6
Sep-1991	24.5	2480	7.75	13.56	6.33	0.87	3.96	9.08	2.18	1.11	12.35	0.27	150.2	1587.2
Oct-1991	26.1	2590	7.96	13.1	6.14	0.83	4.95	9.28	1.3	1.37	13	0.09	99.78	1657.6

Table 57: Chemical and physical analyses for (KTD) Site VII in 1989, 1990 and 1991.

Date	T ˚C	EC µs/cm	pH	Na meq/l	Ca meq/l	K meq/l	Mg meq/l	HCO3 meq/l	SO4 meq/l	NO3 meq/l	CL meq/l	PO4 meq/l	COD mg/l	TDS mg/l
Jan-1989	14.38	1462	7.54	6.07	4.2	0.51	3.6	4.55	3.74	0.627	6.95	1.59	59	935.68
Feb-1989	15	1556	8.4	7.65	5.3	0.52	4.1	6.552	3.271	0.64	8.3	0.24		995.84
Mar-1989	14	1560	8.47	5.502	4.5	0.359	4	4	2.08	0.763	7.25	0.66		998.4
Apr-1989	24	1256	6.6	6.59	4.49	0.03	2.85	4.08	1.5	0.976	6.45	2.32	17.3	803.84
May-1989	24	1651	8.8	7.59	5	0.586	3.7	575	2.98	1.02	7.65	3.70	20.3	1056.64
Jun-1989	24.8	1636	8.92	7.72	4.9	0.64	3.7	4.95	2.56	1	8.33	2.87		1047.04
Aug-1989	27.2	1723	8.8	8.66	5	0.66	3.86	6.1	3.31	0.95	7.7	0.14	101.8	1102.72
Sep-1989	25.6	1840	8.64	7.17	5.1	0.77	4.7	4.49	2.85	0.917	10.2	0.06	362.2	1177.6
Nov-1989	26.2	2110	8.54	9.09	6.2	0.869	5	6.25	2.95	1.23	11.5	0.22	140	1350.4
Jan-1990	15.6	2160	7.69	9.22	6.2	0.72	4.8	5.19	3.86	1.32	10.25	0.17	31.95	1382.4
Feb-1990	12.4	1963	7.78	8.77	4.9	0.72	5.16	6.31	2.52	1.07	9.1	0.33		1256.32
Mar-1990	17.1	1648	7.56	7.4	4.9	0.51	3.5	5.51	2.38	1.11	7.5	0.15	45	1054.72
May-1990	24.8	1830	8.45	8	5.78	0.61	3.82	4.36	2.51	1.32	9.6	0.21	46.56	1171.2
Jan-1991	12.8	2560	7.92	11.67	6.99	0.72	5.35	9.38	1.63	1.13	11.4	0.19	48.7	1638.4
Mar-1991	21.7	1580	8.11	6.43	4	0.46	2.8	5.72	1.38	0.65	5.29	0.10	59.75	1011.2
Jun-1991	24.9	1920	6.34	9.45	5.6	0.72	3.5	6.73	1.82	0.86	9.11	0.25		1228.8
Aug-1991	22	2050	8.06	10.97	6.44	0.92	3.85	7.22	1.84	0.52	10.97	0.22	46.68	1312

دراسة اثر تحسينات المعالجة في محطة الخربة السمرا على نوعية المياه المستقبلة للمياه المعالجة و التربة المروية بها.

- دراسة الأثر البيئي -

إعداد

غيداء العبداللات

المشرف

ألاستاذ الدكتور الياس سلامة

الملخص

في نهاية عام 2007 أنشئت محطة جديدة لمعالجة المياه العادمة لمنطقة "عمان والزرقاء". و المحطة الجديدة ميكانيكية خلافا للمحطة القديمة التي كانت تعمل على مبدى البرك الطبيعية في تحقيق المعالجة.

اما الهدف الرئيس لهذه الدراسة فهو تقييم آثار معالجة مياه الصرف الصحي الجديدة في "الخربة السمرا" على المسطحات المائية على امتداد مجرى نهر الزرقاء، وسد الملك طلال والمناطق الواقعة على مجرى الحبس الأسفل للنهر من سد الملك طلال.

تم جمع عينات من المياه المعالجة من أجل التحليل المخبري في سبعة مواقع بدأ من مخرج محطة الخربة السمرا وعلى نهر الزرقاء حتى سد الملك حيث تمت دراسة التغير في تركيز المكونات في جميع العينات التي تم جمعها. اما الخصائص التي تمت دراستها فهي خصائص فيزيائية و كيميائية بالإضافة إلى فحوصات ال BOD_5 و COD ،و مؤشرات التلوث الأخرى حيث تمت مقارنة هذه القيم مع القيم التي تم قياسها سابقا عندما كانت محطة المعالجة القديمة عاملة.

تعتبر هذة الدراسة من الضرورة بمكان من حيث تقييم الأثر البيئي للمياه العادمة المستخدمة في عمليات الري على طول نهر الزرقاء و منطقة سد الملك طلال وخصوصا تأثيرها على التربة والمياه الجوفية في هذة المناطق.